A Comparative Analysis of Conventional and Emerging Methods for Characterizing Coastal Morphology and Change

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions as accepted by my examiners.

I understand this thesis may be made electronically available to the public.

Abstract

Small islands and coastal areas are threatened by the negative impacts of climate change. Sea-level rise, increased storm event and frequency, and other coastal hazards are expected to impact infrastructure, settlements, and facilities that support the livelihood of coastal communities. In addition, small islands and coastal communities are often considered to lack the capacity to properly anticipate and adapt to a quickly changing climate. Proper coastal adaptation requires a number of key components including data collection, monitoring and evaluation. This thesis sought to evaluate two methodologies of data collection and monitoring on Prince Edward Island, Canada: one low cost method using terrestrial peg line measurement; and two, the use of low altitude small Unmanned Aerial Vehicles (UAvs) to create high resolution orthomosaics and digital surface models for coastal assessment. Considerations of cost, agility and accuracy of the research methods are made throughout the thesis with an intended application to a long-term monitoring program that can be adopted by other small island and coastal communities around the world interested in improving their resiliency and ability to adapt to climate change.

An historical terrestrial measurement method was employed on Prince Edward Island by the Department of Community and Cultural Affairs Marine Environment Section in 1984 but abandoned several years later in the early 1990s. This thesis investigated this method through re-measurement and study of old log books and revealed several inadequacies. Improvements to the historical monitoring method are made through the resurrection and establishment of 74 erosion measuring locations across Prince Edward Island during the 2014 and 2015 field seasons. Measurement of these 74 cliff and bluff coastal environments resulted in an average annual loss of 0.46 m with a single largest loss of 2.69 m. This method is limited by the type of data collection but provides a good starting point for coastal communities with limited knowledge and expertise in the field to begin understanding and quantifying coastal change.

Recent developments in Unmanned Aerial Vehicle technology have led to a wide-spread interest in using the technology across many industries and fields of study. A major advantage of using UAVs is their ability to efficiently collect high resolution orthomosaics and elevation models at a fine temporal scale for coastal assessments. This thesis utilized two UAV systems at a study site in North Lake, Prince Edward Island, Canada - a fixed wing system by PrecisionHawk, and a quadcopter by 3DRobotics - and conducted a comparative analysis to determine the best platform for the application to coastal data collection and monitoring. Results found consistently improved performance of the quadcopter versus the fixed wing, including accuracy, a lower upfront cost, and the ability to perform to expectation in high sustained winds. Some results include an image marker to ground control point difference of 0.10 m for the fixed wing and 0.03 m for the quadcopter. The quadcopter showed better results when comparing elevations to a survey grade GPS survey of the study site, and coastal delineations of the orthomosaics showed a slight improvement using the quadcopter. This comparative analysis showed the real possibility of accurately representing a coastal cliff or bluff environment using UAV technology that can be monitored to detect annual change. The ability of UAVs to cost-effectively and accurately produce data rich products leads to the conclusion that the technology provides a realistic alternative to traditional monitoring methods and has great implications for the adoption to monitor coastal environments of small islands and coastal communities.

Acknowledgments

This study was funded by the University of Prince Edward Island, the Mi’kmaq Confederacy of PEI, the Partnership for Canada-Caribbean Climate Change Adaptation (ParCA), and the Prince Edward Island Department of Communities, Land Environment. Field work was supported by the UPEI Climate Research Lab and the field assistance from Derek Ellis, Evan MacDonald, Scott Bray, and Andrew MacDonald is greatly appreciated.

I would like to thank my thesis supervisor - Dr. Adam Fenech (University of Prince Edward Island) - my thesis committee members - Dr. Nick Hedley (Simon Fraser University) and Dr. Sheldon Opps (University of Prince Edward Island), and my external reviewer – Dr. Norm Catto (Memorial University of Newfoundland) for their time and commitment to this important work. Special thanks to Don Jardine of the UPEI Climate Research Lab for his involvement in this work through his extensive knowledge of PEI’s history and environmental expertise. Mr. Jardine’s willingness to work with others and advance PEI’s capacity to adapt to climate change has not gone unnoticed. Finally, I would like to thank friends and family for their support throughout my academic career especially during my Master’s Degree.

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List of Acronyms

DEM – Digital Elevation Model

DSM – Digital Surface Model

DTM – Digital Terrain Model

GIS – Geographic Information System

GCP – Ground Control Point

GNSS – Global Navigation Satellite System

GPS – Global Positioning System

IPCC – Intergovernmental Panel on Climate Change

LiDAR – Light Detection and Ranging

NRTK – Networked Real Time Kinematic

RTK – Real Time Kinematic

sUAS – small Unmanned Aerial System

TAR – Third Assessment Report

TLS – Terrestrial Laser Scanning

UAV – Unmanned Aerial Vehicle

VTOL – Vertical Take Off and Landing

Chapter 1

1.1 Introduction

Coastal areas and small islands are vulnerable to the human-induced effects of climate change. In particular, sea-level rise is expected to threaten infrastructure, settlements and facilities that support the livelihood of coastal communities through exacerbated inundation, storm surge, erosion, and other coastal hazards (Nurse et al, 2014). The Fifth Assessment Report (AR5) of the IPCC (Intergovernmental Panel on Climate Change), the leading authority on climate change, contains a chapter on the challenges faced by small islands due to climate change (Nurse et al, 2014). The IPCC report notes that settlements and infrastructure are mostly located in coastal areas of small islands and are highly vulnerable to sea-level rise and high energy waves and storm surges. A loss of coastal amenities coupled with temperature and rainfall changes has the potential to greatly affect the vital tourism industry of islands. Cultural assets are also considered to be at risk (Nurse et al, 2014).

The intention of this thesis was to investigate alternatives to common data collection methods in coastal areas by assessing two methods - a conventional (peg line) and emerging (UAV) ones for characterizing coastal morphology and change. The purpose of investigating these methods was to determine if low cost, agile approaches to coastal mapping and monitoring are accurate enough to detect annual changes over many study sites. The motivation of this work was to provide low capacity small islands and coastal communities with a means to record and quantify coastal change to build resilience and enhance adaptation capabilities under a changing climate.

This thesis focuses on Prince Edward Island, Canada, an island province similar to the small islands described in the IPCC AR5. The conclusion made by the IPCC AR5 was for small islands to focus urgently on enhancing resilience and adaptation implementation holds true (Nurse et al, 2014). An assessment of the IPCC Technical Guidelines for coastal adaptation by Klein et al (1999) proposed a broad framework approach to coastal adaptation assessment: (i) information collection and awareness raising; (ii) planning and design; (ii) implementation; and (iv) monitoring and evaluation (Klein et al, 1999). The focus of this thesis is on the development and assessment of a terrestrial and an airborne method for addressing information collection and monitoring of the coastal adaptation approach. Information collection and monitoring of coastal erosion on Prince Edward Island is detailed in Chapters 2 and 3 of this thesis. Chapter 2 investigates the use of peg-line terrestrial measurements of coastal erosion in cliff and bluff environments across Prince Edward Island and its application to a long term monitoring program. Chapter 3 is a comparative analysis of two UAV (Unmanned Aerial Vehicle) platforms for collecting airborne imagery to generate high resolution orthomosaics and DSM (Digital Surface Models) of a cliff environment along Prince Edward Island's north shore. This chapter addresses the accuracies of the generated data and the development of a methodology for the application to long term coastal monitoring using UAVs. Together this work aims to build upon previous efforts made on Prince Edward Island to document, monitor, and disseminate coastal change information. The methods explored in this work intend to address challenges of long term monitoring at small temporal and spatial scales. Considerations of cost and capacity are a major theme of this work. The methods investigated in Chapter 2 and 3 were chosen based on the limited cost and staff required to collect and process data across many study sites.

Methods are assessed based on several criteria including; cost, time, accuracy, skills required, regulations, data output, and feasibility to implement Island wide. It is hypothesized that UAV technology can be effectively applied to coastal environments and prove the most viable solution to accurately detecting coastal cliff and bluff erosion at small spatial and temporal scales.

1.2 Background

1.2.1 Coastal Change Methodologies on Prince Edward Island

The negative impacts of climate change on Prince Edward Island are expected to be most prevalent along the coast (Fenech, 2016). Accelerating relative sea-level rise coupled with projections of increasing storm intensity and declining winter ice cover in the southern Gulf of St. Lawrence suggests an increase in coastal erosion hazards (Forbes et al, 2004). Millions of dollars in damage to harbour facilities, coastal tourism infrastructure, and damage to private homes occurred during three major storms in the southern Gulf of St. Lawrence in 2000-2001 through storm surge flooding, wave action, and sea-ice run up (Forbes et al, 2002). Storms can also cause geomorphological changes such as beach, dune, and cliff erosion. Understanding of natural responses to environmental forcing is required for coastal management practices and realistic ability to predict shoreline change (Forbes et al, 2004).

Recent work conducted by Webster and Brydon (2012) on Prince Edward Island studying coastal change examined black and white orthophotos from 1968 and colour orthophotos from 2010 where the coastline was defined at metre increments. Webster and Brydon (2012) defined the coastline as the most landward influence of the ocean. For the purposes of this thesis, a modified definition of coastline is used to describe the seaward edge of land along a cliff top.

Moreover, Webster and Brydon (2012) calculated distance of change by interpreting and mapping the coastline from orthophotos across multiple years. Rates of change were then calculated based on when the orthophoto datasets were collected (Webster, 2012). A Geographic Information System (GIS) was used to complete the analysis resulting in an average rate of erosion of 0.28 m/year between 1968 and 2010. Direction of coastline change determined erosion and accretion of the coastline and were included in the above calculation. Anomalous areas defined as areas with rates higher than +/- 3 m per year were not included in the final tally (Webster and Brydon, 2012). This study provided an historical rate of change that is now used by provincial government officials for coastal management practices such as decision-making regarding issuing building permits, and determining set-back regulations. Currently, while there are exceptions to these general rules, the set-back regulation for a given property seeking a building permit shall be no closer than 75 feet or 60 times the annual rate of erosion, whichever is greater, to a beach, measured from the top of the bank (Planning Act - Subdivision and Development Regulations). Levels of risk were generated by Webster and Brydon (2012) using the results of their study: High Risk: great than 90 cm/year; Moderate Risk: 30 – 90 cm/year; Low Risk: less than 30 cm/year. Levels of vulnerability (high, moderate, and low) of coastal infrastructure on Prince Edward Island have also been generated using the results of this study by multiplying the metre increment change by 30, 60, and 90 year projections (Fenech *et al*., submitted 2016) which assumes a linear progression of historical rates of erosion. This assumption introduces potential issues and uncertainties particularly in areas where high rates of change were found around low lying marsh land. The interpretation of the coastline between 1968 and 2010 can suggest a large change when the extent of a salt marsh changes but will not necessarily persist because of the topography. These inconsistencies present an opportunity for improved data collection methods that can lead to better decision-making. Additionally, province-wide orthophotos are captured by the Department of Forestry every 10 years for updating the provincial forest inventory and use across departments (PEI State of the Forest Report, 2010). This time scale lacks the ability to study annual coastal change and the influencing effects of climate change; particularly sea-level rise and increased storm severity. Annual changes are necessary to track areas of coastal risk and vulnerability (Boak et al, 2005). A supplementary approach at a finer time scale can improve the ability to manage the coastal zone.

Additional work for monitoring and resolving a rate of coastal change on Prince Edward Island was started by Prince Edward Island's Department of Community and Cultural Affairs Marine Environment Section in 1984. This method involved taking annual terrestrial measurements using a measuring tape from known landmarks or installed angle iron stakes to the coastline at locations across the province. The differences in annual measurements were used to quantify coastal change to give a rate of change for a given study site. This method continued until the early 1990s at which point the coastal change monitoring program was mostly abandoned as seen in the field notes in Appendix A .

1.2.2 Application of UAV to the Coastal Zone

Small Unmanned Aerial Systems (sUAS) or Unmanned Aerial Vehicles (UAV) have seen a dramatic increase in use for studying the environment (Whitehead et al, 2014). (Note: UAV (Unmanned Aerial Vehicle) refers directly to the aircraft whereas sUAS (small Unmanned Aerial System) encompasses all components required for flight including but not limited to aircraft, ground control station, data link, and sensor.) sUAS provide researchers with a relatively low cost tool ($4,000 - $40,000) that enables the collection of high resolution airborne spatial data at many temporal scales. Previously, orthorectified aerial images or digital elevation models (DEM) were generated using data captured using either manned aircraft or satellites. Compromises of cost, spatial scale, and temporal scale were something researchers needed to work around. Improved image-matching algorithms, battery technology and design, and automated mission control software has enabled the potential for sUAS to become a reliable alternative to traditional spatial data collection methods. UAV have been applied for research to mining (for example, Lejeune et al, 2013), forestry (for example, Immerzeel et al, 2014), animal pattern movements (for example, Zmarz, 2014), and glacier dynamics (for example, Tong et al, 2015) with several papers focused on assessing the accuracy of photogrammetrically-derived elevation models (Douterloigne et al, 2010, Harwin and Lucieer, 2012, Hugenholtz et al, 2013). Additionally, application of sUAS to river channels and coastal environments has been studied by Flener et al. (2013) and Mancini et al. (2013).

Flener et al. (2013) used UAV technology coupled with terrestrial mobile LiDAR to develop a method for creating high resolution digital terrain models (DTM) of river channels and their floodplains. UAV were flown to create an image-based bathymetric model of the river bed and photogrammetrically-derived point cloud of the study site (Flener et al, 2013). Terrestrial mobile LiDAR was used in river channel mapping where turbidity was low. UAV were controlled manually leading to challenges in coverage. UAV reliability was also a challenge as a UAV malfunction resulted in the UAV ending up in the river during the first campaign (Flener et al, 2013). GCP (Ground Control Points) were used to validate the sUAS data and resulted in under 10 cm spatial and elevation errors. Ultimately, data from several sources were combined successfully to map the river channel between 2010 and 2011 where a change detection analysis using transects was able to map geomorphological differences of the river channel. This study concludes that a UAV-only approach may be preferred combining photogrammetry point clouds for dry areas and bathymetric modelling for inundated areas (Flener et al, 2013).

Mancini *et. al.* employed the use of sUAS for a beach dune system in Marina di Ravenna, Italy as they sought a rapid, inexpensive, and automated method for producing a dense point cloud and subsequent DSM (Digital Surface Model) (Mancini et al, 2013). Comparison of the data to a Terrestrial Laser Scanning (TLS) survey and GNSS (Global Navigation Satellite System) survey was used for validation. Results of the vertical comparison showed very little difference between the sUAS and TLS DSM (0.015 m) suggesting the vertical accuracy of the sUAS dataset is comparable to the industry accepted TLS (Mancini et al, 2013). Eighteen ground control points were used for the hex-copter survey of a 200 m wide dune system. Mancini et al. concludes that the sUAS workflow provides a promising alternative to expensive, time consuming data collection methods for deriving DSM in dune environments. Mancini et al. noted that difficulties can arise in sudden topographic changes in slope and that assessment of different geomorphic environments is required (2013).

Chapter 2

Terrestrial peg line measurements for monitoring coastal erosion of cliff and bluff environments on Prince Edward Island, Canada

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Target Journal: Ocean and Coastal Management or Environmental Monitoring and Assessment

Abstract

Prince Edward Island, Canada in the Southern Gulf of St. Lawrence has historically experienced high rates of coastal erosion that threaten homes, cottages, lighthouses, wells, septic systems, roads and other infrastructure. Expected impacts of climate change on the Island include increased storm severity and frequency, and sea-level rise leading to an increase in the vulnerability of coastal infrastructure. A sharp increase in sea-level rise after 2004 at Charlottetown, PE affirms these concerns. As a result, there exists a need to consistently monitor and quantify coastal change across the province on an annual basis. The objective of the work outlined in this chapter was to collect coastal change data along the province's cliff and bluff coastal environments for application to an annual monitoring program. In order to do this, a low cost, low technology method was employed at measuring locations across the Island. The terrestrial peg line measuring method is based on an historical erosion monitoring program established and run by the Department of Community and Cultural Affairs Marine Environment Section in 1984 until the early 1990s. Historical study sites were re-measured during the 2014 summer field season where possible using the methods outlined in the historical field notes. Improvements were made to the methods to improve accuracy and sustainability of the program and constitute the beginning of a new erosion monitoring program across Prince Edward Island. Seventy-four cliff top measurement locations were measured during the 2014 and 2015 field season resulting in an average loss of 0.46 m. Twenty-four additional sites were added in 2015. The largest single loss of 2.69 m was observed at Wood Islands Lighthouse. It is recommended that this monitoring program continue to grow for many years as a supplement to other coastal monitoring initiatives to understand the long term impacts and trends of coastal change in an uncertain changing climate.

Acknowledgments

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2.1 Introduction

Coastal environments are experiencing the adverse effects of climate change from sea-level rise and extreme events (Nicholls and Cazenave, 2010). The coast of PEI is no exception and has been identified as one of Canada's most vulnerable coastlines to sea-level rise (Forbes et al, 2002). Coastal hazards on PEI are influenced by sea-level rise, tides, storm surge, and wave action and effect, and result in coastal erosion, coastal flooding, and damage to coastal ecosystems (Davies, 2011). Generally, erosional processes are dictated by wave energy, wind, surface run-off, and ground water flow (Irvine, 2014). The sensitivity of PEI's coastline can be attributed to a few main factors: fragile sandstone bedrock; sandy, dynamic shore zones; indented shoreline with extensive salt marsh; low backshore terrain with increased flooding potential; high rate of shore retreat; and ongoing coastal submergence (Hawkins, 2007) and rising sea levels (Webster, 2012). PEI's susceptibility to coastal change has long been recognized (Armon and McCann, 1977, Avery, 2005, Webster, 2012, Forbes et al, 2002) including a report by Forbes *et. al.* in 2004 that found variability in time and location of coastal erosion rates along a sample study site on the North Shore of PEI in the Southern Gulf of St. Lawrence. Cliff erosion rates less than 1 m / year (slow and persistent) to 2.5 m/year or greater (more variable) were found (Forbes et al, 2004).

Despite the work studying the sensitivity of PEI's coast, no comprehensive annual coastal monitoring program has been in place. Coastal monitoring over a range of temporal and spatial scales has been recognized by the Intergovernmental Panel on Climate Change (IPCC) as an important aspect to understanding the effects of climate change (Nicholls and Cazenave, 2010). This chapter introduces a Provincial historical monitoring program and assesses the practicality and benefits of resurrecting, improving, and maintaining a low cost, agile coastal monitoring program using direct field measurements of cliff top pins.

A geomorphic shoreline classification of Prince Edward Island's roughly 3,300 km (Davies, 2011) coastal and estuarine shoreline length (coastal – 800 km, estuarine – 2,500 km) showed that 52% of the Island's open coasts are represented by cliffs and bluffs while 31% is sand dune. Wetlands dominate estuarine shorelines representing 54%, with cliffs and bluffs at 24% and low plains at 12% (Davies, 2011). The data collection method described in this chapter focuses primarily on coastal monitoring of cliff and bluff shore types, both defined as vertical, high steep banks of rock and soil faces on the shore. However, conclusions will be drawn on the effectiveness to monitor other representative shore types such as low plains, sand dunes, and wetlands.

A recent study (Webster and Brydon, 2012) interpreted the entire coastline of PEI at metre increments using orthorectified aerial photos from 1968 and 2010 datasets. The resulting distance measurements were calculated as a rate of change in metres per year. Over this 42 year period, an average rate of coastal change of -0.28 m/year was calculated, the negative rate representing erosion. This approach to coastal change monitoring provides a good baseline; however, quantifying annual coastal change through a comprehensive field measurement method aims to better understand the year-to-year processes leading to coastal erosion. Note that the province acquires orthophotos every decade (PEI State of the Forest Report, 2010). Therefore, erosion rates can first be updated using Webster's method in 2020 should this approach be chosen. This chapter will provide the framework for continuous monitoring of coastal sites to present reliable estimates of coastal erosion in cliff and bluff environments and highlight areas sensitive to coastal erosion.

Generally, measuring cliff or bluff erosion rates can be categorized into 4 different methods with varying degrees of accuracy, expense, and expertise required. These methods include: oblique and vertical aerial photography (Dolan et al., 1991, Wray et al., 1995, Forbes et al, 2002, Webster, 2012); airborne laser scanning (Forbes et al, 2004, Mitasova et al, 2003, Day et al, 2013); cartographic measurements using historical maps (Gray, 1988, Camfield and Morang, 1996, Addo et al, 2008); and direct field measurements (Amin and Davidson-Arnott, 1995, Gulyaev and Buckeridge, 2003, Day et al, 2012, Irvine, 2014, Baptista et al, 2008). Direct field measurements can include profiling techniques, repeated surveys, or, in the case of this study, cliff and bluff top edge pin measurements. A coastal edge pinning method was first implemented on Prince Edward Island in 1984 by the Prince Edward Island Department of Community and Cultural Affairs Marine Environment Section over concerns of the rates of coastal erosion and the impact of sand mining on these rates. Original field books and site logs were obtained and digitized in 2014. The original study consisted of 50 measuring locations - 15 in Kings County, 26 in Queens County, and 9 in Prince County – which form the basis of this thesis work both in locations and methodology. During the field season of 2014, original log books and methods were used to re-measure all sites where pins could be found. Thirty-four measurements of historical measuring locations were made that correspond to an average annual rate of erosion of 0.40 m/year at those locations from 1984 to 1996. Improvements to the historical methodology were made through the establishment of 16 new sites and 40 measuring locations at the end of the 2014 field season. Although there have been significant improvements made in global positioning system (GPS) technology since the original method was developed, and use of the technology is standard in terrestrial monitoring methods of the environment (Baptista et al, 2008, Harley et al, 2011, Ollerhead et al, 2013, Irvine, 2014), the spirit of the simple low cost, low technology original method was maintained throughout this study.

Coastal variability and erosion-accretion trend analysis is essential across coastal disciples including scientists, engineers, and managers (Boak et al, 2003). Due to the dynamic nature of the coastal boundary, a functional definition of the coastline is required to study any temporal change. Traditionally, the coastline is considered to be the water-land intersection, however, a range of coastal indicators dictated by temporal and spatial scale are needed for practical purposes (Boak et al, 2003). Coastline identification involves the definition and selection of a coastal indicator feature, used as a proxy for the true coastline position (Boak et al, 2003). For the purposes of this thesis, the seaward edge of land along the top of a cliff or bluff is used as the coastal indicator feature. The figure below demonstrates a range of possible indicator features where "A" is the coastal indicator used in this study.

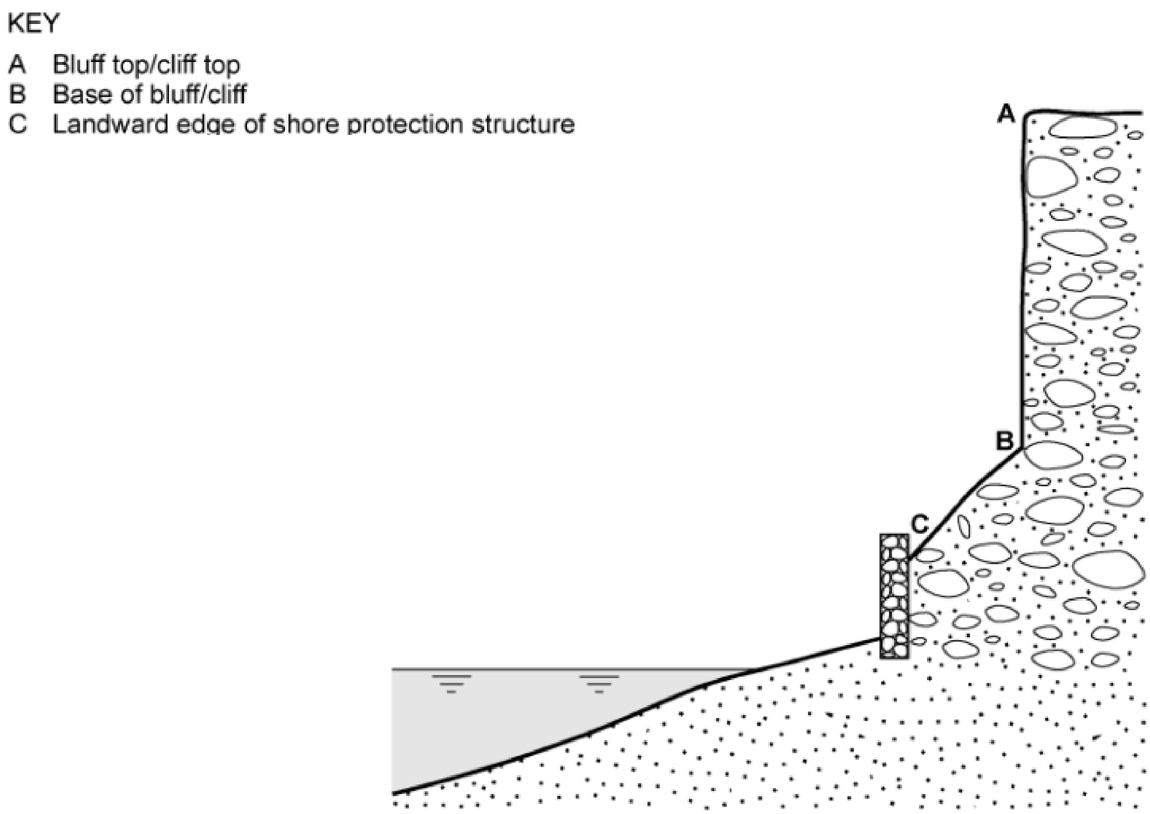

Figure 1: Range of commonly used shoreline indictor features for a cliff or bluff coastal environment. Consistent definition of the coastline through use of a coastal indicator feature is necessary for reliability in change detection. Figure taken from Boak et al, 2003.

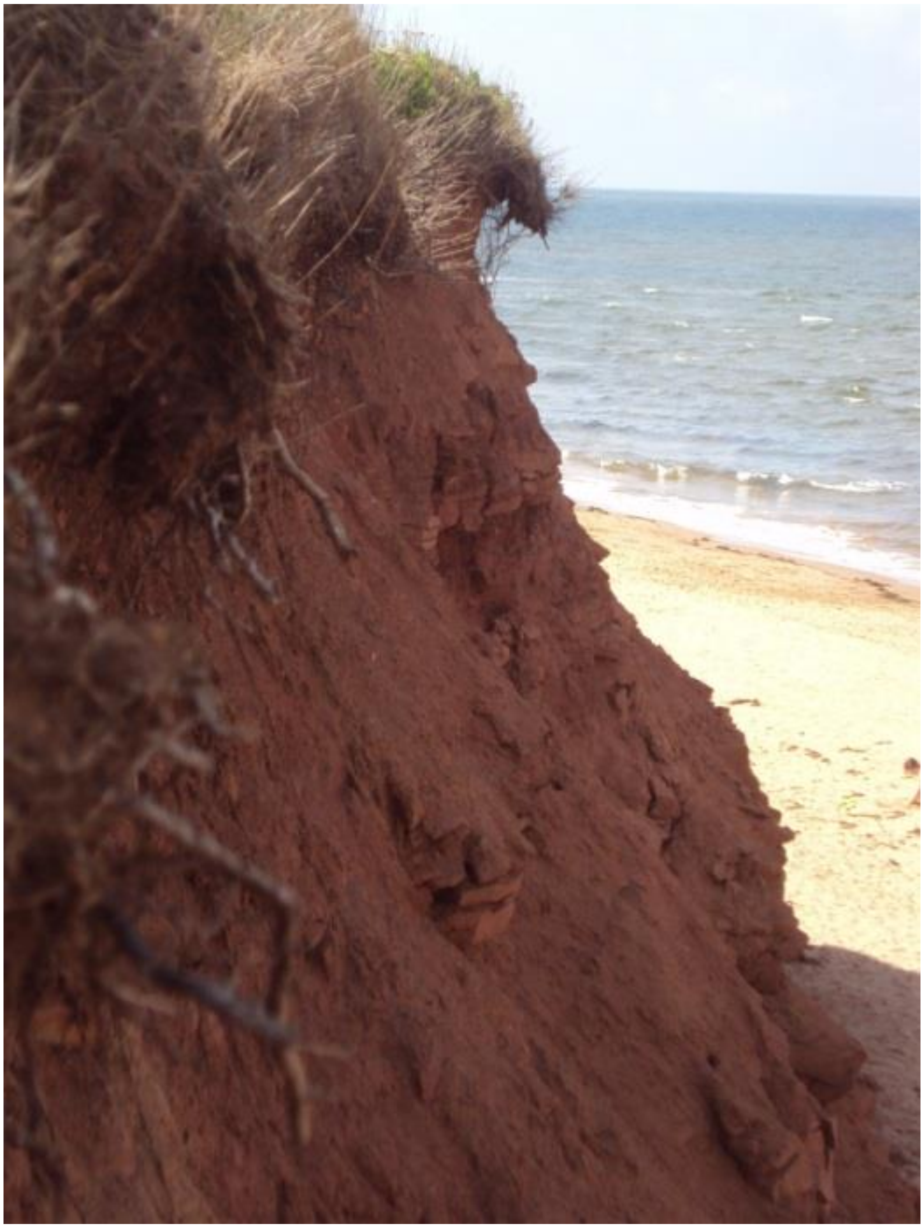

Figure 2: Cliff top slumping seen at Thunder Cove, PE study site.

Figure 2 above demonstrates common representative cliff top slumping at Thunder Cove, PE. A major source of uncertainty arises from the interpretation of the coastal indicator feature and whether to include slumping in the measurement. Therefore, the methods outlined in this study attempt to provide a clear and consistent approach for reducing edge errors.

Gulyaev and Buckeridge (2004) describe the difficulties in specifying the exact edge of a cliff environment in a paper on terrestrial methods for monitoring cliff erosion. Uncertainties exist using airborne photography, and laser scanning as well as terrestrial methods including those used in this study.

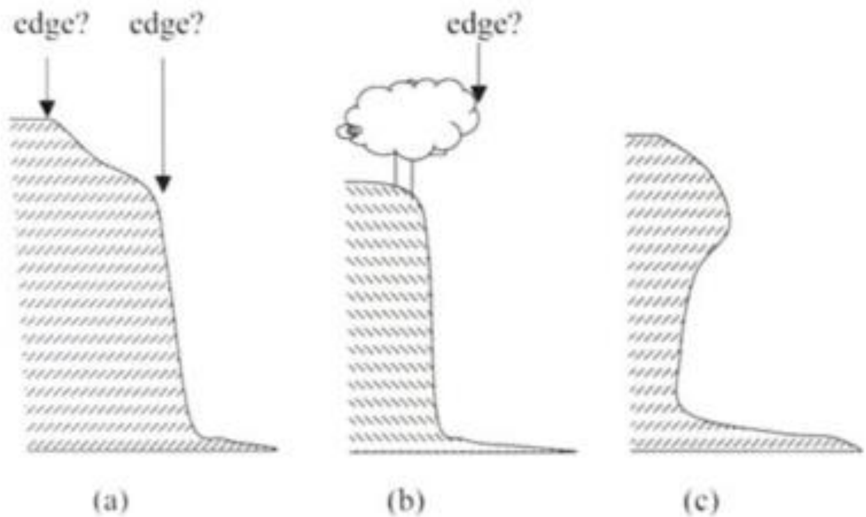

Figure 3: Illustration of potential cliff edge definition issues. Scenarios A and C are common issues for terrestrial peg line measurements. Scenario A demonstrates sloping of the cliff edge where scenario C demonstrates slumping or overhanging of a cliff edge. Scenario B demonstrates and edge definition issue when using airborne photography. Figure taken from Gulyaev and Buckeridge, 2004.

2.2 Methods

2.2.1 Field Methodology

A wide array of techniques can be applied to measure coastal geomorphology. Methods can range from low-cost repeated measurement of pins or peg-lines to more advanced terrestrial or airborne measurements. The former was utilized throughout this study to quantify rates of erosion at 74 peg-line measuring locations across Prince Edward Island. Log books from the historical coastal erosion monitoring program established in 1984 and managed by the Department of Community and Cultural

Affairs Marine Environment Section indicate a version of a cliff top pin measuring protocol was implemented. Digitization of the log books during the 2014 field season was followed by the re-measurement of 34 of the 50 original measuring locations. In some cases, measurements had not been taken for 20 years and pin locations were either lost to erosion or overgrown by thick vegetation and could not be located. Also, the historic monitoring program did not always use pins as a reference. It was common for measurements to be taken from existing structures like the corner of a lighthouse, cottage deck, or monument and then simply “in the direction perpendicular to the shoreline”. For this reason it was determined that improvements to the methodology had to be made as monument reference points could be altered. Prince Edward Island has a long history of moving lighthouses back from an eroding shore, or property owners might install a new cottage deck or construct some repairs over a period of time. Because large intervals of time are needed to estimate coastal erosion with significant confidence, according to Gulyaev and Buckeridge (2003), the variability in reference points needed to be addressed and improved. Below is a sample log sheet describing a site measured from a structure that is subject to move and direction of the measurement to be taken, “perpendicular to the shoreline”.

DEPARTMENT OF COMMUNITY & CULTURAL AFFAIRS

MARINE ENVIRONMENT SECTION

SHORELINE EROSION SURVEYS

LOCATION: NAUFRAGE

OBSERVATION SITE NUMBER: K-9

DATE ESTABLISHED: 30/10/84

DETAILED LOCATION DESCRIPTION: THIS SITE IS LOCATED AT THE NAUFRAGE LIGHTHOUSE.

REFERENCE DESCRIPTION: DISTANCE WAS MEASURED FROM THE NORTH ~~WEST~~ EAST CORNER OF LIGHTHOUSE, THEN PERPENDICULAR TO THE SHORELINE.

U.T.M. COORDINATES: E 54435 N 514626

DATE OBSERVED	DISTANCE TO SHORELINE	OBSERVER
30/10/84	124'-4"	PHILIP WARD
12/06/85	124-0	
29/05/86	123-8	
1/06/87	123-0	
28/04/89	117-3	
29/11/95	114-0	ADM PKW
NOV 7/96	114-0	PW JT
Aug10/98	106-3	JT, JD
Aug 19/99	99'-2"	JT, CQ, DM

1.4'

(See attached photo)

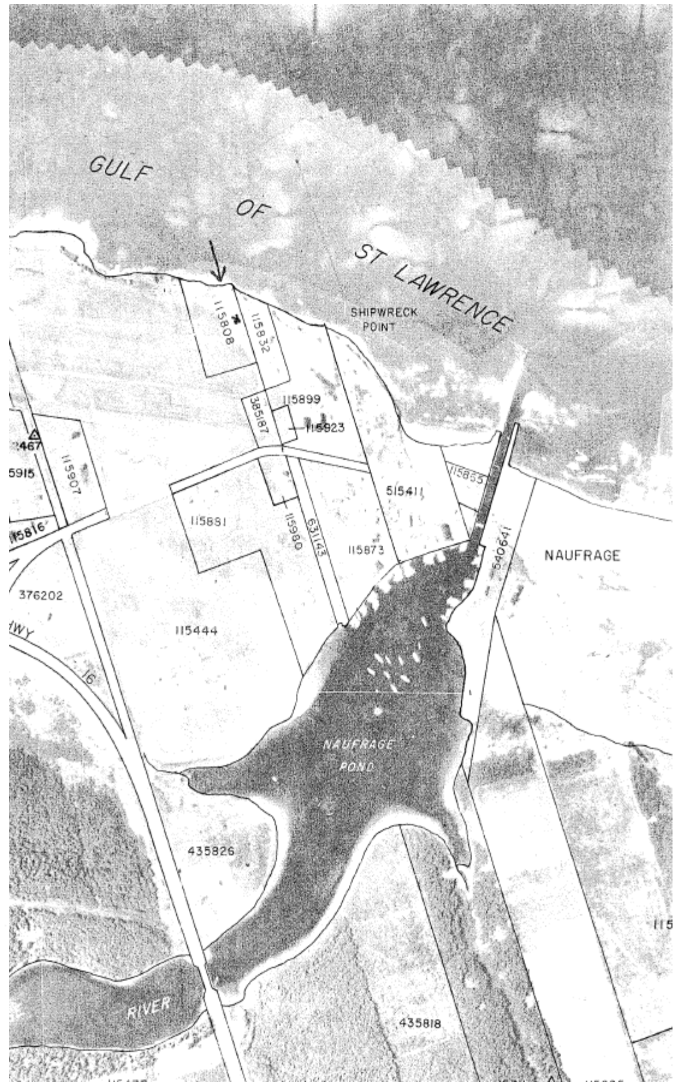

Figure 4: Historic monitoring program log sheet at Naufrage, PE. The notes indicate the measurement to be taken from the north east corner of a lighthouse. Measurement line is unclear and if the lighthouse is moved the measurement reference point will be lost.

“Perpendicular to the shoreline” proved to be too vague for accurate annual measurements as it relied too much on the interpretation of the field crew to determine the angle of measurement without sufficient reference points. The angle at which the measurement is taken will affect the distance value of the measurement and can result in different locations being measured over time; therefore, a new approach to measurement direction is required. As a result of the lessons learned during the 2014 historical erosion monitoring program resurrection, an improved peg-line methodology was developed that sought to simplify the protocol, reduce error, limit impact on study sites, and eliminate measurements from structures that could be potentially moved, increasing the longevity of the program.

In practice, the approach involves physically hammering two roughly 1 metre (m) lengths of 15 millimetre (mm) diameter metal rebar “pins” into the ground in a line spaced 10 m and 20 m roughly normal to the coast and manually taking a measurement to the coastal indicator feature using a measuring tape. The improved method begins with a site assessment identifying access, human activity nearby, and any vegetation that may impede with accurate measurements. A new study site typically has three measurement locations spaced evenly along the coastline of the study site. This is to increase the amount of data points and get a better overall picture of coastal erosion at any given site. It is possible for no change to occur at one set of stakes compared to a loss at another set of stakes metres away. Generally, two sets of stakes will be established along the apparent property lines normal to the coast with the third set established roughly in the middle of the property lines. This number of measurement locations is believed to be the least invasive approach to property owners while still providing sufficient data points.

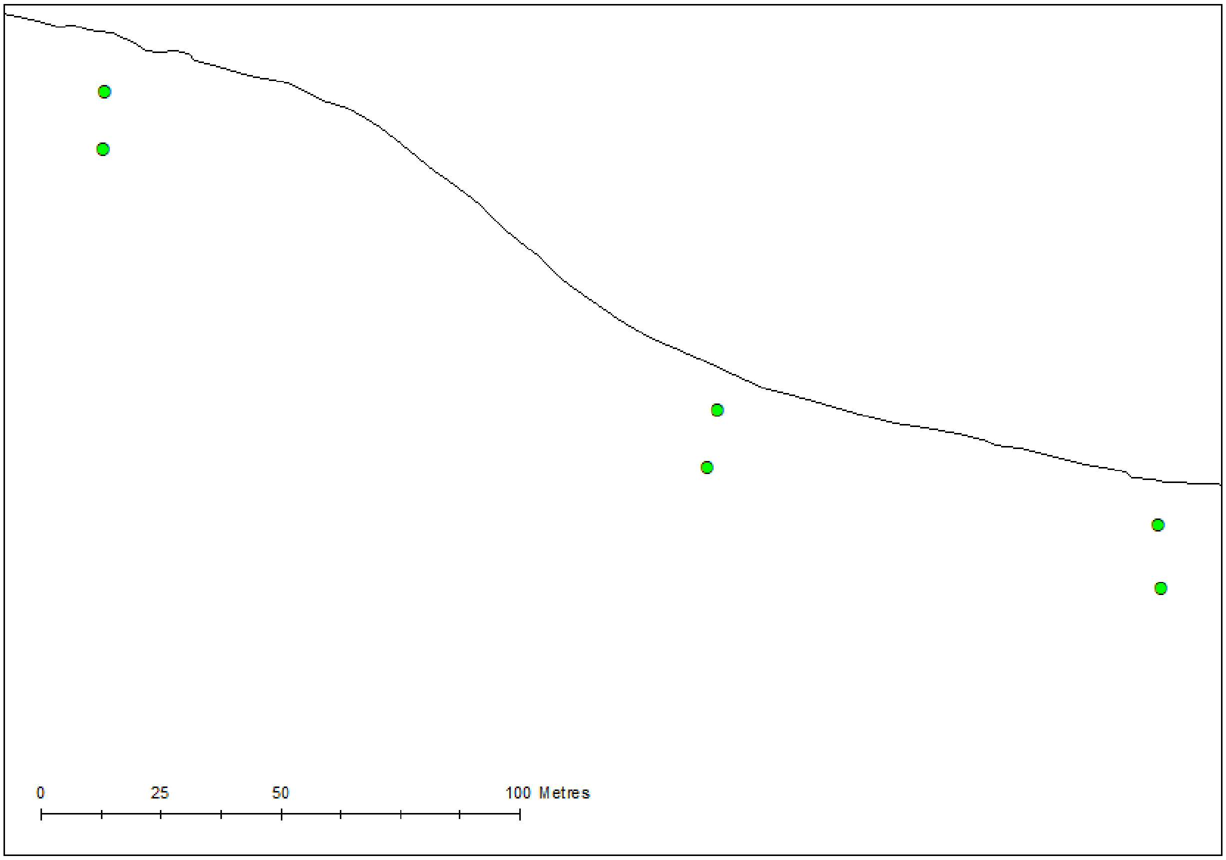

Figure 5: A typical distribution of measuring locations at a newly established site. Points represent the set of pins from which the measurement is taken. Study site – North Lake, PE.

At each measurement location, the metal rebar pins are driven into the ground using a metal mallet at 10 and 20 m intervals perpendicular to the coastline. The methodology allows for some flexibility in the placement of the pins based on a site's characteristics which is determined during the site assessment. Measurements are taken, using a 100 m measuring tape, from the front stake (10 m) where the back stake (20 m) is used to line up with the front stake to ensure the same measurement line is used each time (Irvine, 2015). The metal rebar is either pounded flush with the ground or left raised based on the site assessment. Often property lines contain overgrown vegetation and the pins need to be left raised in order to find them and to create a straight line with the measuring tape over the low vegetation. Metal caps, see Figure 6, are hammered on the ends of the rebar using a rubber mallet just before the desired depth is achieved. Following installation, a final measurement is taken to eliminate any errors that may have occurred during installation. Measurement is taken from the center of a cap. Measurements are recorded in a log book along with a cliff height estimate. The site's geology and characteristics are described and pictures of the study site are taken for reference.

Figure 6: "UPEI Climate Research Lab" metal rebar caps.

Global positioning system (GPS) locations of each stake are taken using a Garmin eTrex recreation grade GPS for general site mapping and locating stakes year-to-year. The accuracy of this unit does not allow for any direct measurements to be taken, however, it is common (Boak et al, 2005, Ollerhead and Davidson-Arnott, 2012, Irvine, 2014) to see peg-lines measured using professional grade GPS which would improve mapping accuracies and reduce errors. Professional grade GPS would instantly increase project startup cost significantly as well as ongoing costs and expertise required (Boak et al, 2005, Hawkins, 2009). A typical centimetre grade RTK-GPS can cost upwards of $20,000+ plus another $20,000+ for a base station or alternatively a subscription to a network based correction service for $1,200/year. In keeping with the tradition of the historical monitoring program, the use of expensive technology was not included in this aspect of the study.

At each historical study site, only one measurement location had ever existed. The improved methodology requires multiple peg-line measurements to be taken at each study site to get a better representation of erosion along a stretch of coastline. After measuring all historical sites possible and developing an improved methodology, 40 new measuring locations were installed at the end of the 2014 field season at 16 study sites. During site selection, there was a focus on filling gaps in the program to get a better distribution of PEI's cliff and bluff coastal environments. Ultimately, site establishment rested on land owner permissions. As a result, many new locations were set up on land owned by the Nature Conservancy of Canada, Provincial Parks, or local residents with an expressed interest in the monitoring program. During the 2015 field season, measurements were taken at all 74 new and operational historic sites. At this time new measuring locations were installed at historical sites according to the improved methodology for a uniform monitoring program moving forward. Fifteen (15) new sites were also added to the program consisting of 24 measuring locations during the 2015 field season. Following the 2015 field season, a total of 98 measuring locations exist at 50 historical and new study sites.

Time spent at each study site varies with average time spent being about 30 minutes per site. Difficulty finding pins or establishing new measurement locations tend to increase time at a study site. Driving times also vary but most sites can be visited within an hour or less driving time from Charlottetown, PE. Sites in the same geographic region can be visited on the same day to driving time. The western part of the Island can take two hours of driving from Charlottetown and is a possible reason for the lack of study sites in this area.

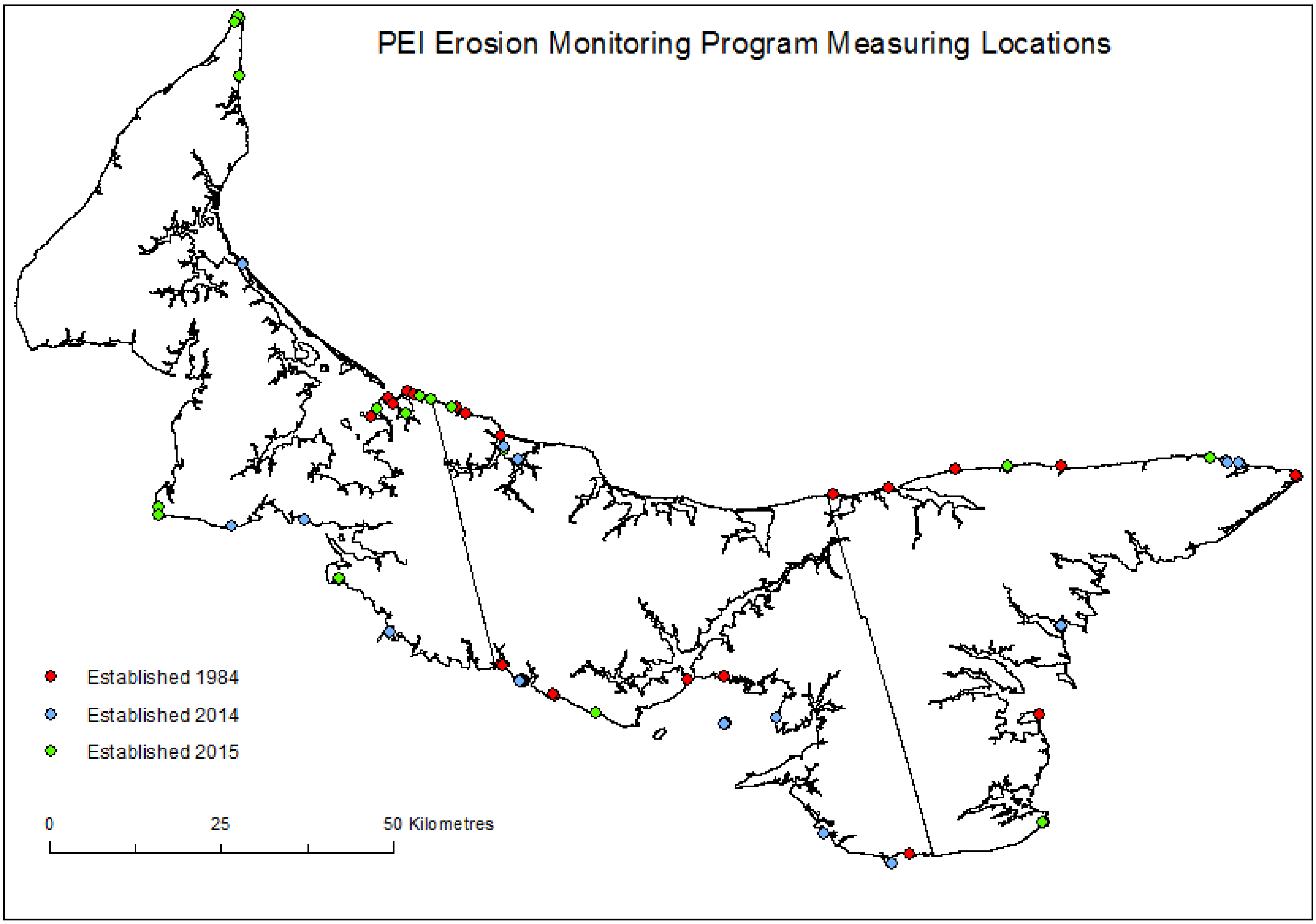

Figure 7: Distribution of erosion monitoring sites across PEI. Red- historical sites, Blue – sites established 2014, Green – sites established 2015. Significant gaps exist in monitoring sites along the western coasts of the Island as well as gaps along the north shore that are dominated by dunes systems and operated by federal authorities.

The focus of this study was on cliff and bluff environments along Prince Edward Island's coastal areas. Below is a diagram demonstrating a typical profile of this type of environment.

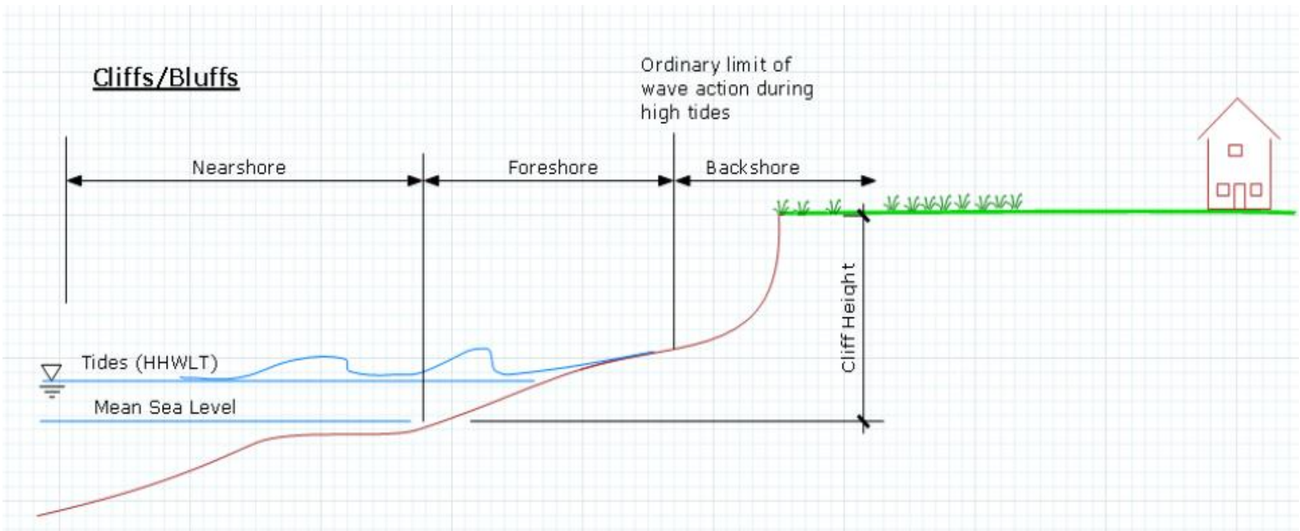

Figure 8: Profile of a typical cliff or bluff coastal environment. Cliffs and bluffs have a definitive edge from which measurements can be made. Measurements are taken along the peg line to the cliff top edge represented above by the left extent of the horizontal green line. Image taken from Cold Water Consulting's shoreline classification of PEI.

In practice, this method requires minimal expertise and training lending itself well to summer student work. The developed methodology calls for the measurement to be taken from the first instance of solid land of the cliff or bluff top edge. If there is a large overhang occurring at the edge, the measurement is to be taken from the point directly above the point in which the edge is no longer part of the overhang. This is illustrated in Figure 9. An understanding of edge effects is needed by all crew members taking measurements. It can be tough and even dangerous to identify exactly how much undercutting is occurring. When considering these sources of error, this study has experienced uncertainties up to +/- 0.20 m introduced mainly through human error when measuring and determining cliff edge.

Accuracies will depend on how much care is taken to ensure a straight measuring tape and how the cliff or bluff edge is interpreted. It is very typical for this type of coastline to experience overhanging or cracking at the edge of the cliff or bluff as seen below in Figure 9.

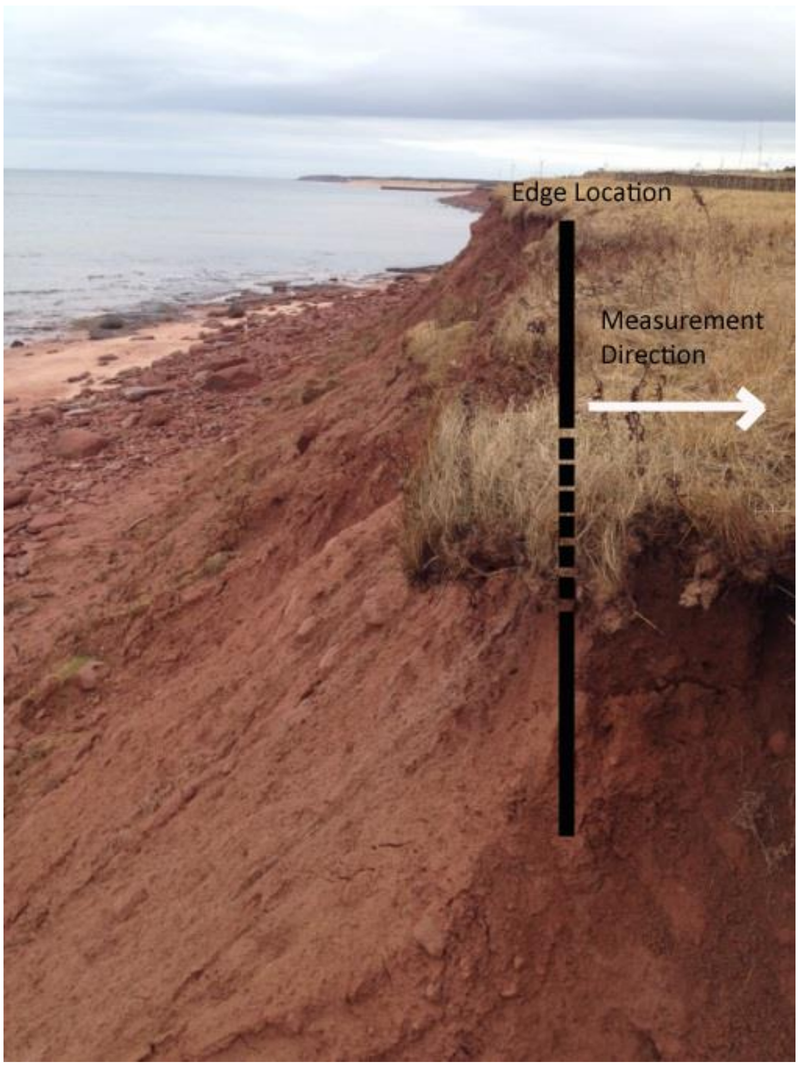

Figure 9: Edge measurement location of a typical study site at North Lake, PE. This demonstrates that the furthest edge is not always where the measurement should be taken from. The edge, in this case, would not be able to support any weight and is therefore left out of the measurement.

The historical methodology had several sites where data was collected for other coastal types (dunes, wetlands) which were outside the scope of this study and were not included in final calculations. This is because a clear coastal indicator feature cannot be resolved using the terrestrial manual measurement method employed in this study. That is, a clear beginning of a dune, for example, cannot accurately be identified on the ground from year-to-year in many cases. Additionally, measurement of a dune system would require direct interaction with the sensitive environment which is discouraged on Prince Edward Island.

2.2.2 Data Analysis

A table (see Appendix A) was first created from the digitized log books. Included for each coastal monitoring site was the date established with subsequent dates when measurements were taken corresponding to distance from coastline values in metres. Global positioning system (GPS) locations, cliff height, field crew, and any notes taken were also included in the table. Thirty-four (34) of the 50 historical measuring locations were measured in 2014. Data from these locations were added to a master table that includes all newly established measuring locations from 2014. This resulted in 74 measuring locations for the 2015 field season. Sites established in 2015 were added to the master table for the following field season. From the master table, an average rate of erosion was calculated between 2014 and 2015 field seasons based on the difference in yearly measurements.

GPS locations were used to create a point data shapefile of all measuring locations using ArcGIS's 'Add XY Data' function to visualize the spatial distribution. The distribution can be seen in Figures 7 and 11. Furthermore, a shapefile (Figure 10) created by Cold Water Consulting in 2010 divides Prince Edward Island into 17 littoral cells or coastal compartments used to describe a shoreline classification of the coast resulting from the influence of winds, waves, currents, and sea-level changes - shoreline units within which sediment transport processes are either partially or completely contained (Davies, 2010).

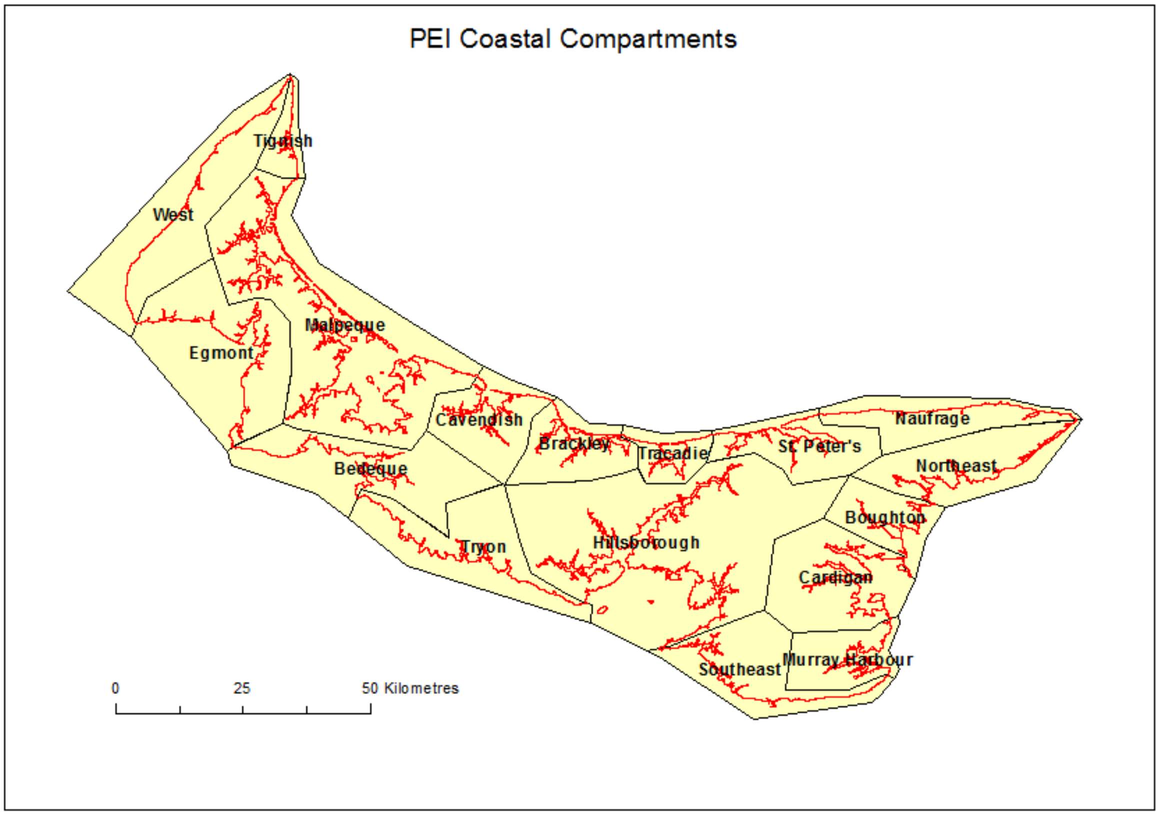

Figure 10: PEI's 17 coastal compartments or littoral cells based on sediment transport processes, providing a framework for coastal interpretation.

This was overlaid with the measuring locations shapefile which allows for the separation of erosion rates based on littoral cell. The spatial distribution of study sites across littoral cells can be seen below in Figure 11. Measuring locations were "clipped" by the littoral cell boundaries using the ArcGIS "Clip" geoprocessing tool. For the purpose of demonstrating a data analysis method, a sample of littoral cells with the most number of measuring locations was extracted. Changes measured between 2014 and 2015 were calculated for each of these littoral cells. Erosion rates at select historical sites were calculated and plotted to investigate trends over time and serves to further demonstrate an analysis method that can be used on data collected in the future. Select sites were chosen based on consistent historical annual measurements.

The majority of measuring locations were contained within 3 littoral cells; 23 in Tryon, 19 in Malpeque, and 15 in Naufrage. Malpeque and Naufrage coastal compartments are located along the north shore while Tryon coastal compartment is located along the south shore. The Malpeque shoreline extends from Cape Kildare to Cape Tryon and includes the Cascumpec and Malpeque estuaries. Naufrage extends east from Cable head to East Point. Tryon extends west from Rice Point to Seacow Head (Davies, 2010).

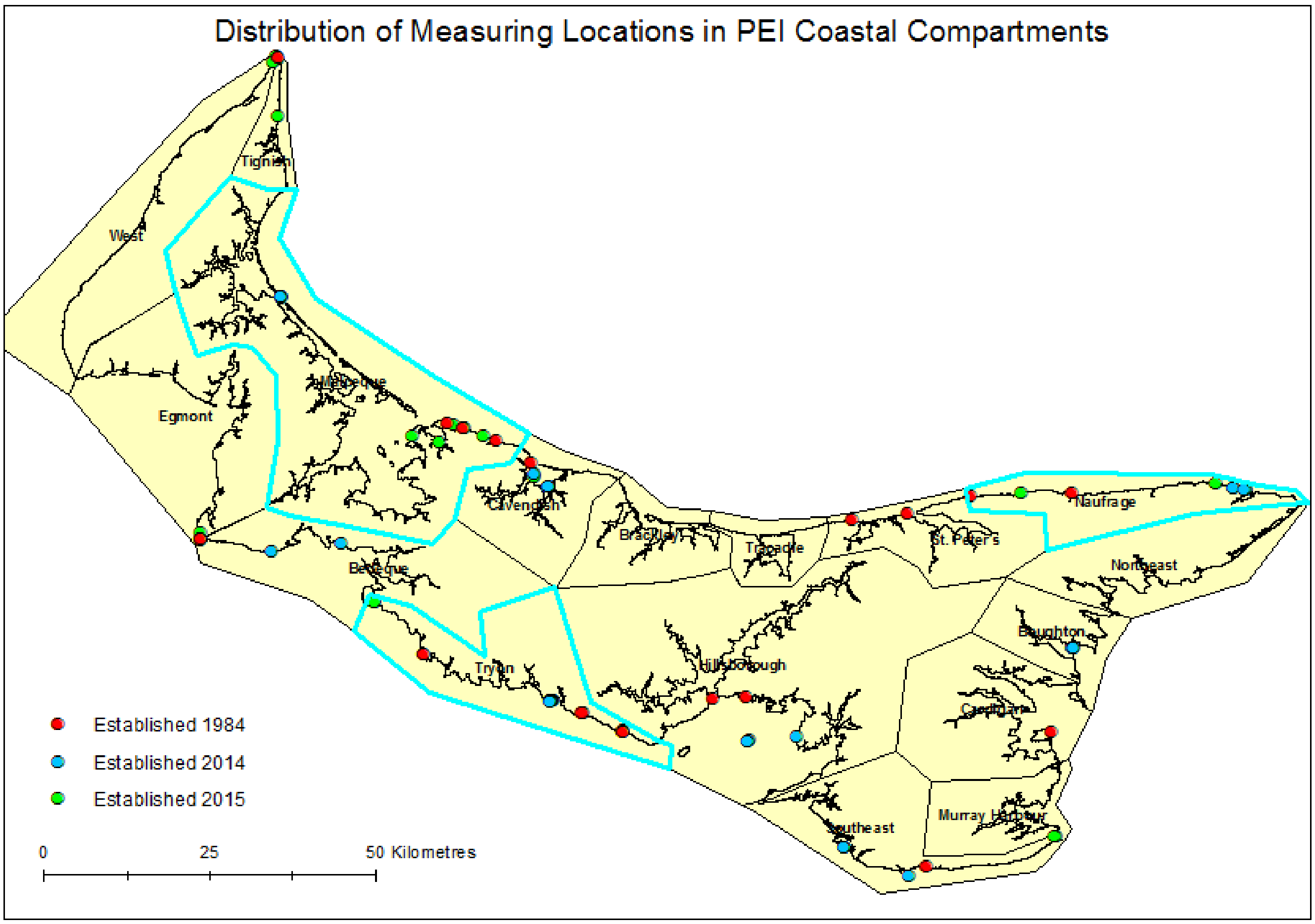

Figure 11: Distribution of historical and new sites in relation to coastal compartments. Historical study sites fall mainly within three coastal compartments (highlighted) with additional sites being added to these three coastal compartments in 2014 and 2015. Ongoing efforts will distribute new study sites across all coastal compartments.

2.3 Results and Discussion

The average total difference, corresponding to erosion, in measurements taken at 74 cliff-top measuring locations across Prince Edward Island between the 2014 and 2015 field seasons was 0.46 m. Of these locations, 14 experienced little to no change (< 0.5 m), 9 experienced greater than 1 m of erosion, and 4 experienced a loss of over 2 m. The largest loss observed was 2.69 m at the Wood Islands Lighthouse, pictured below. Note: For simplicity, the number of days between measurements was not considered opting for an annual rate with the intention that this method is to be applied over longer periods.

Figure 12: Image taken at the Woods Island Lighthouse monitoring site where the greatest single erosion rate was observed over the 2014-15 field seasons.

Grouping study sites by coastal compartment resulted in three littoral cells of particular interest; Tryon along the south shore, and Malpeque and Naufrage along the north shore. Each cell experiences the influence of wind, waves, currents, and sea-level uniquely; therefore, erosion rates for each cell were calculated separately. Tryon (pictured below) contains the most measuring locations of any littoral cell with 23 total (6 newly established) with 17 measurements taken between 2014 and 2015. Based on these 17 measurements, an average loss of 0.17m occurred. The highest single loss of 1.43m occurred at Argyle Shore Provincial Park.

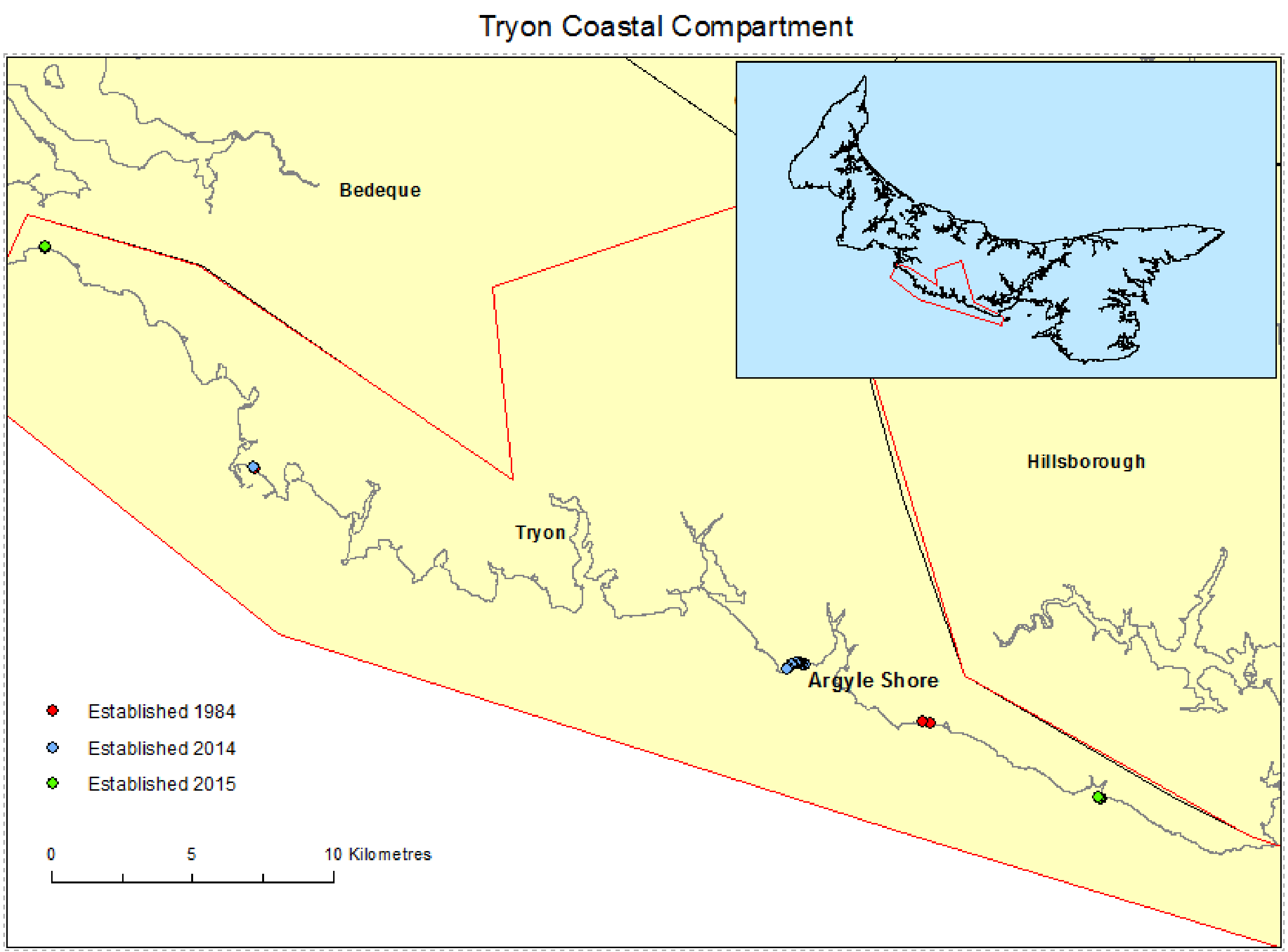

Figure 13: Map of Tryon coastal compartment with all measuring locations. The single largest instance of coastal erosion between 2014 and 2015 occurred at Argyle Shore.

Along the north shore in the Malpeque coastal compartment, a total of 14 locations were measured in 2014 and 2015 with 5 new locations added in 2015. The average loss across these locations was 0.40 m with highest instance of loss, 2.31 m, occurring at Seaview.

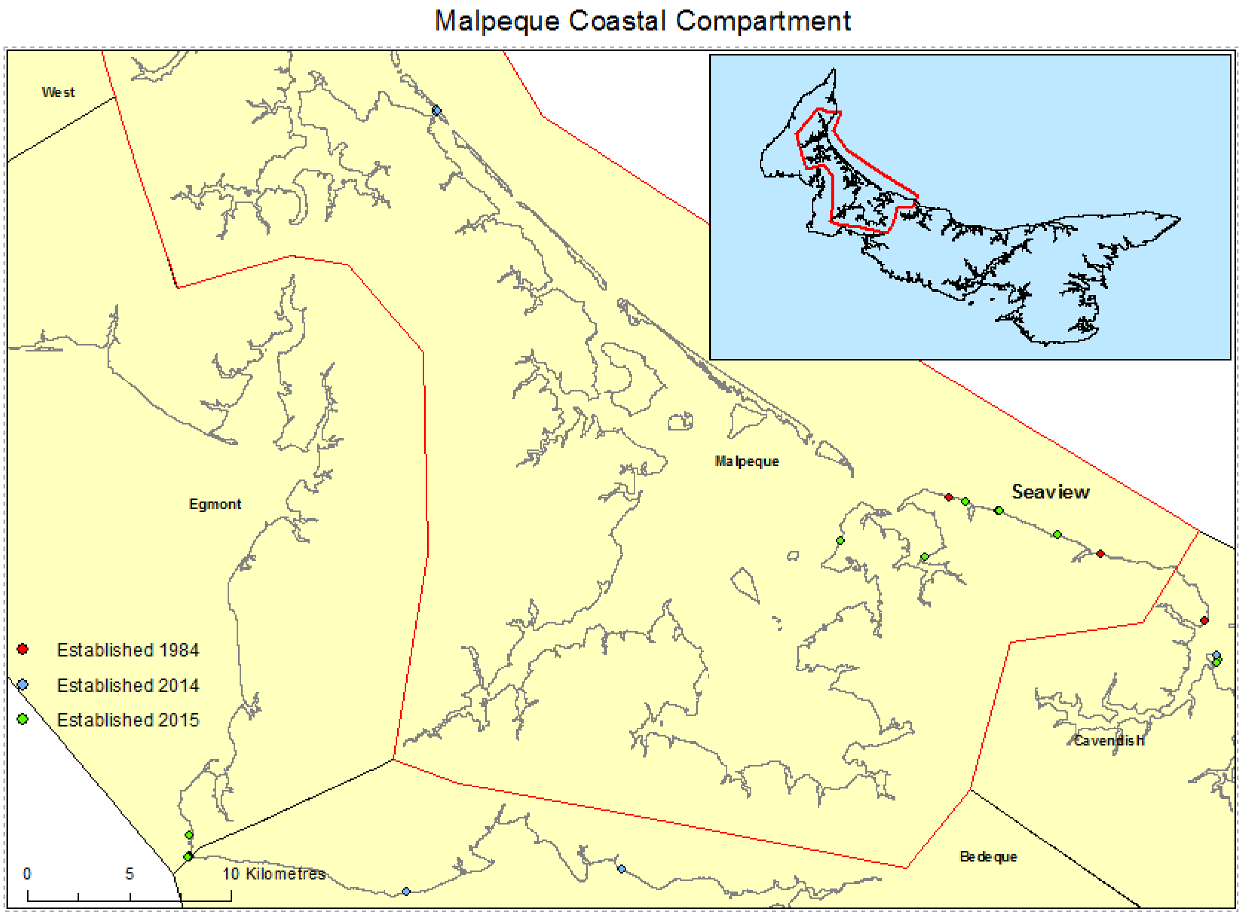

Figure 14: Map of Malpeque coastal compartment with all measuring locations. The single largest instance of coastal erosion between 2014 and 2015 occurred at Seaview.

At Naufrage, 13 measurements were made with the addition of 2 locations in 2015. The average loss between the 2014 and 2015 field seasons was 0.55 m. The largest single loss of 2.56 m was observed at Naufrage Lighthouse.

Naufrage Coastal Compartment

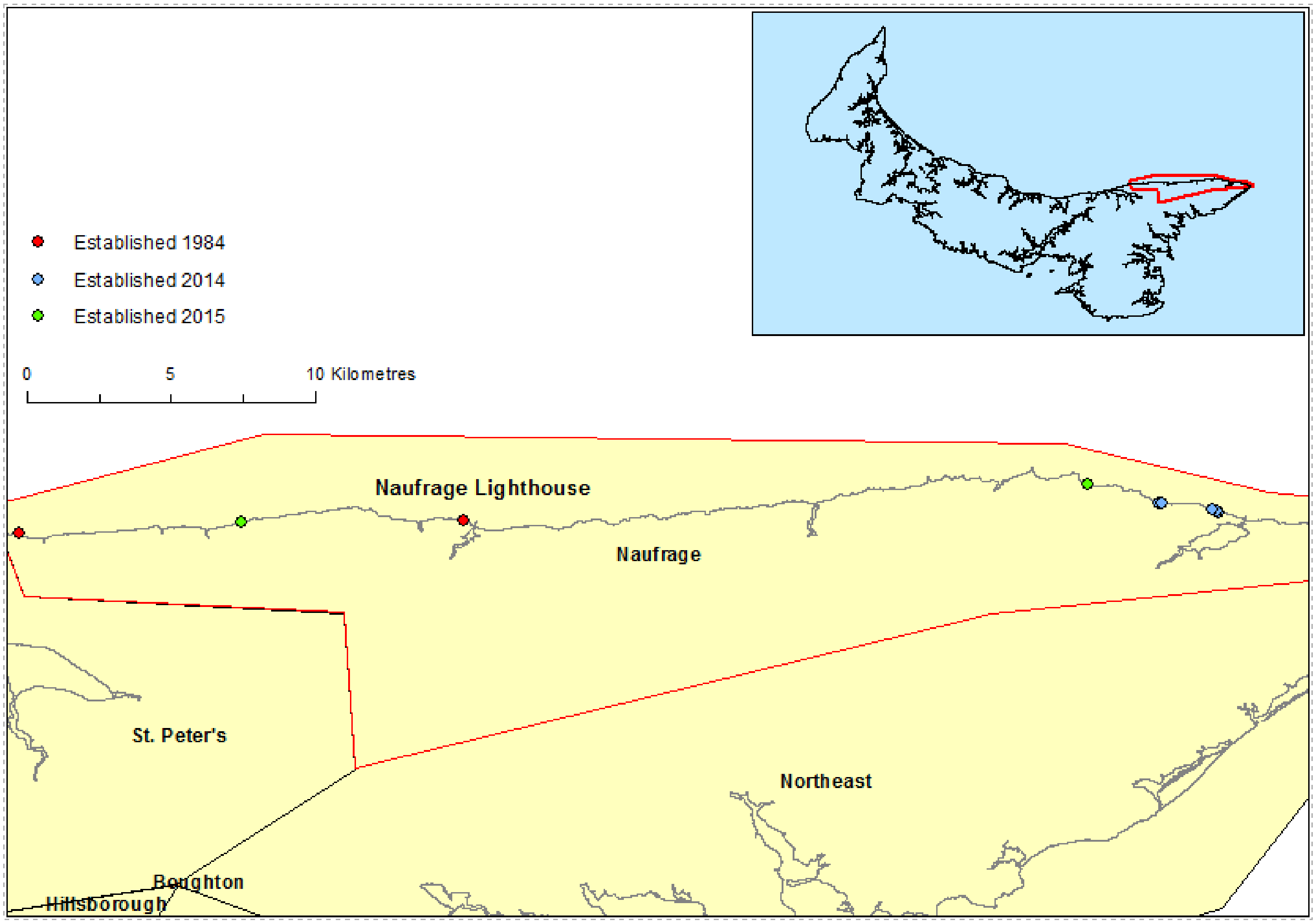

Figure 15: Map of Naufrage coastal compartment with all measuring locations. The single largest instance of coastal erosion between 2014 and 2015 occurred at Naufrage Lighthouse.

Area (Number of Locations)	Average Erosion (2014-2015)
Total Province (74)	0.46m
Tryon (17)	0.17m
Malpeque (14)	0.40m
Naufrage (13)	0.55m

Table 1: Summary of observed erosion between 2014 and 2015 by major coastal compartments and overall total.

Analysis of the data reveals rates of coastal erosion that vary across the Province. The use of the improved method and attention to accuracy has meant that consistent data collection has only spanned a 1-year time interval. Therefore, it is too early to provide quantitative analysis of the data and not possible to predict long-term trends of coastal erosion (Irvine, 214). Short-term data in natural environments can lead to over or under estimations where long-term data is needed to smooth out any variability (Irvine, 2014). Also, the selection of sites was based on the historical study and further sites of opportunity. They were selected based on the observed erosion or erosion concern, and therefore cannot necessarily be considered representative of overall Island erosion.

Furthermore, the existence of the historical monitoring program on Prince Edward Island provides useful data on past erosion estimates and trends. Of the original 50 measuring locations, measurements have begun at 34. Historical sites were established in 1984 by Phillip Ward, employee of the Prince Edward Island Department of Community and Cultural Affairs Marine Environment Section. Measurements are consistently taken on an annual basis at all sites for 5 years until 1989 where a gap in data collection exists until 1996. At this time, inconsistencies begin to develop where some sites have data but others are not re-measured until 1999. Following 1999, most monitoring ceases with the occasional data point in the early 2000s. The majority of all measurements were made by the same person over this timeframe, Philip Ward. Sample plotting of the historic data over the 1984-1990s timeframe reveals historical trends and erosion rates.

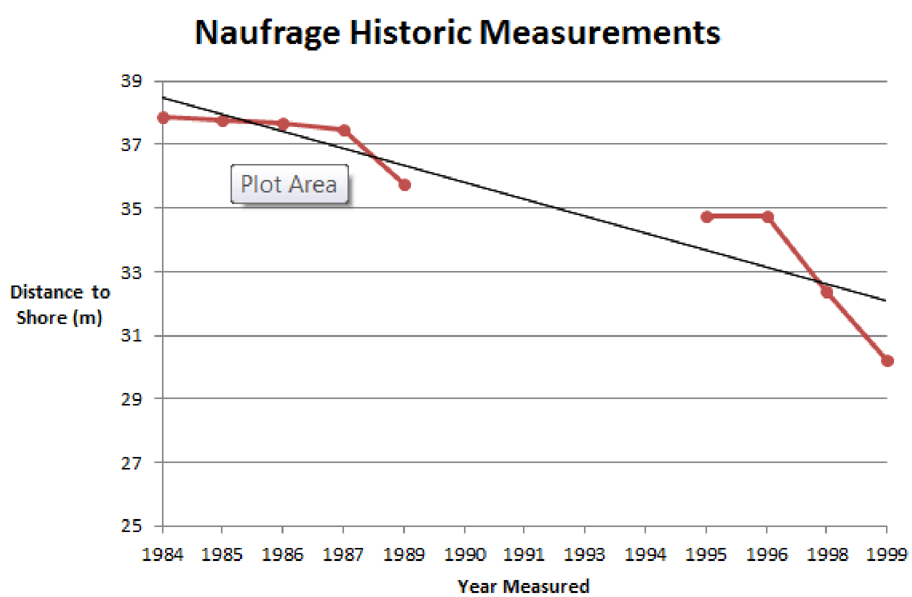

Figure 16: Plot of historical measurements taken at Naufrage.

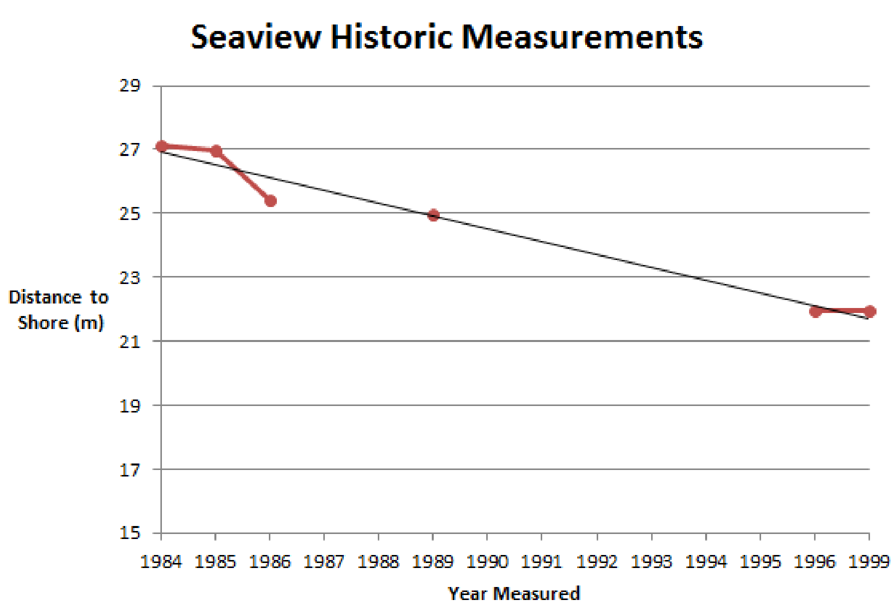

Figure 17: Plot of historical measurements taken at Seaview.

The above graphs show the historic measurements taken between 1984 and 1999. The historic erosion rate at the Naufrage site in the Naufrage coastal compartment was calculated as 0.5 m/year with 9 measurements taken over 15 years with a total loss of 7.67 m. The historic erosion rate at Seaview in the Malpeque coastal compartment was calculated as 0.35 m/year with 6 measurements taken over 15 years with a total loss of 5.18 m.

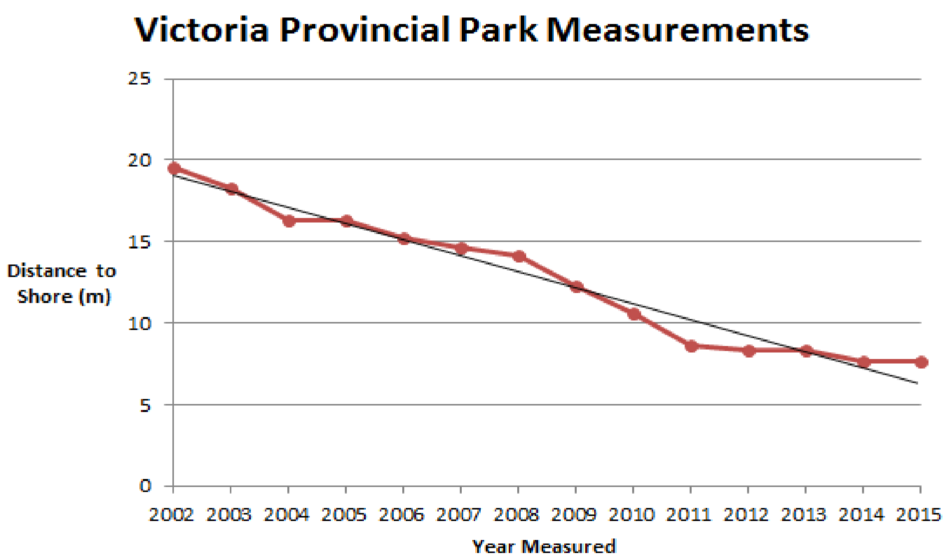

Figure 18: Plot of historical measurements taken at Victoria Provincial Park.

The above graph, showing historical coastal change at Victoria Provincial Park was established outside of the original monitoring program but was measured annually from 2002 until 2014 where it was adopted for this study and measured again in 2015. Victoria Provincial Park is contained within the Tryon coastal compartment and has experienced 12 m of cliff top erosion over the 14 years of direct measurement corresponding to an average annual loss of 0.91m. The consistency of data collection at the Victoria Provincial Park serves as a good example of the value of long-term coastal monitoring.

Now, during the early 2010s data begins to appear again in the historic records although with some anomalies. Figure 20 and Figure 21 demonstrate this and is common throughout the records. A sharp uptick of the distance to shore is seen during the early 2010s which would suggest accretion, a growing of land.

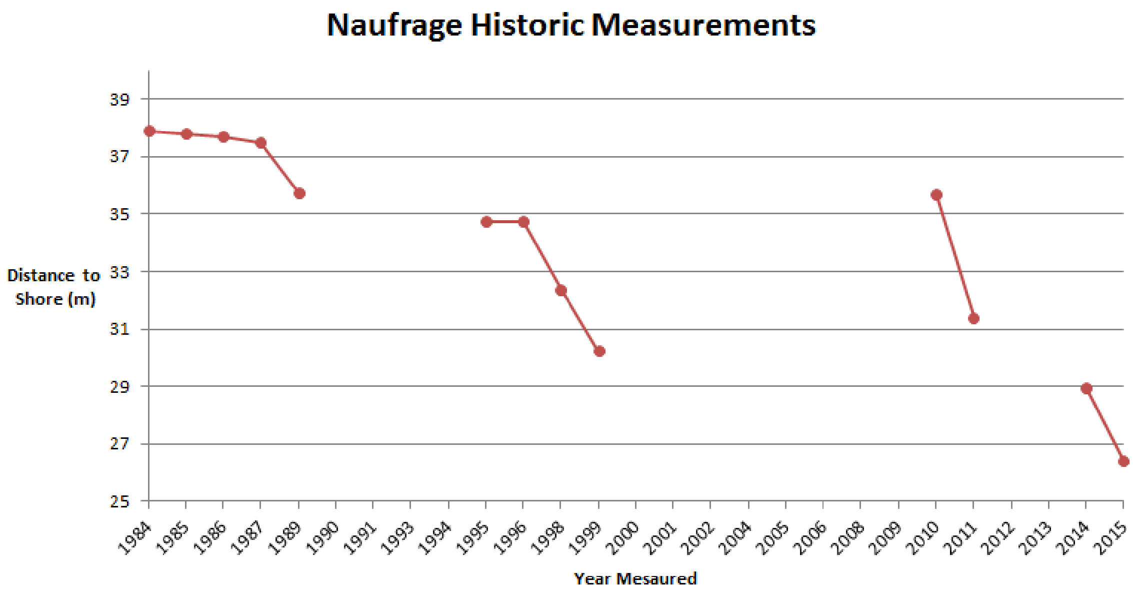

Figure 19: Demonstrating the effect of an inconsistent method and interpretation of how a measurement is to be taken at Naufrage. X-axis represents only the years in which measurements were taken.

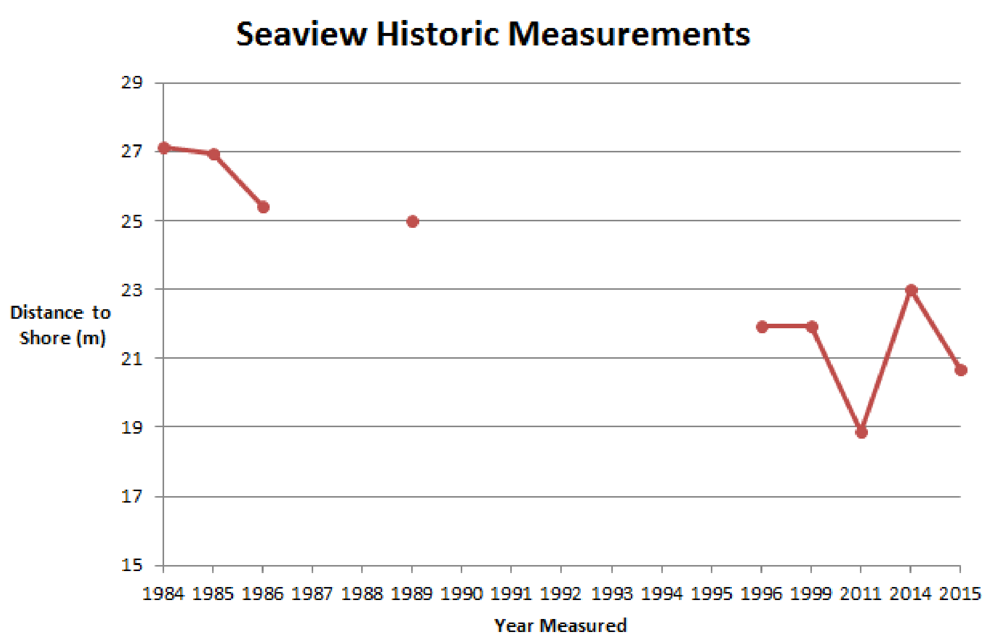

Figure 20: Inconsistencies in the data at Seaview suggest a problem with the methodology. X-axis represents only the years in which measurements were taken.

It is not likely for a cliff to "grow" in this manner over the given timescale so this uptick introduces concern in the reliability of the data. When considering a bluff, a debris flow could result in a gentler slope with an apparent new edge having moved seaward and vertically downward. However, the monitoring method accounts for this by requiring the measurement to be taken from the top edge. Furthermore, the Naufrage and Seaview study sites are steep vertical cliffs; therefore, there was likely a misunderstanding of the original field notes or newly established reference points at the same locations due to overgrowth of vegetation or any number of possible changes to the site over the 10-year period. Measurements around this period are sparse and due to the uncertainty and inconsistency, these measurements were removed from the master dataset. As a result, the resurrection project of 2014 is considered the new start date of a Province-wide coastal erosion monitoring program where methods and reference points are known.

Using orthorectified aerial imagery, an average rate of coastal change across the entire Province was calculated to be -0.28 m/year, representing erosion, from 1968 and 2010 with a higher erosion rate of 0.40 m/year between 2000 and 2010 (Webster, 2012). These rates include areas that experienced accretion and are not specific to a particular coastal environment (Webster, 2012). No claims can be made to suggest that erosion rates have increased since this study was completed but it does lend some credibility to the validity of the simplified terrestrial method outlined in this chapter to provide rates similar to those using alternative methods.

Peg-line measurements provide a reliable and cost effective way to monitor change in coastal cliff and bluff environments. Training time, time-at-site, and data processing time are limited which will help to encourage the long-term adoption of the program and are benefits of simple, direct terrestrial measurements over more sophisticated airborne or terrestrial measurement methods. More sophisticated methods tend to require a higher level of expertise and training across varying temporal and spatial scales (Boak et al, 2005). Generally, data output of more sophisticated measuring methods (aerial imagery, LiDAR) will be more useful to investigators across disciplines including engineers, scientists, managers, policy and decision makers. Data output products could include time series imagery, digital elevation models, or GIS vector data. This presents a limitation of the method outlined in this paper being that only point data is collected at each measuring location. Assuming the improved method is used, a typical stretch of 50-100 m of coastline will only be represented by 3 data points. It is possible this may lead to a misrepresentation of the erosion, for example, if a large section of cliff or bluff were to erode between measurement locations it would not be quantified using this method. This differs from other methods in the literature that utilize airborne imagery for comparisons over time (Webster, 2012) or terrestrial measurements that use Real-Time Kinematic (RTK) global positioning system (GPS) (Baptista et al, 2008, Harley et al, 2011) that are able to delineate stretches of a coastline and compare line data over time. More sophisticated methods also provide the capabilities to monitor Prince Edward Island's other representative coastal environments including sand dunes, low plains, and wetlands. In the case of sand dunes and wetlands, direct measurements are made more difficult by the terrain and ability to definitively indicate a coastal indicator feature. Disturbing sand dunes on Prince Edward Island is discouraged and installation and repeated measurements in a wetland would be impractical.

Therefore, long-term peg line measurement provides a low cost, efficient way to estimate erosion rates across Prince Edward Island's coastal cliff and bluff areas; however, accuracies of these measurements must be considered. A goal of this study was to limit the amount of error in measurements and provide a consistent methodology and protocol that can be used for annual monitoring over many years. A major improvement made to the methodology was to introduce peg lines at all locations. Although difficult to find at times, this approach provides a clear measurement line to the shore that is free of interpretation of the field crew. This is expected to reduce errors over the long term greatly. However, major sources of error remain in the form of edge interpretation and measuring tape straightness. Importance of the measuring tape arises when pins are left raised out of necessity due to surrounding vegetation. As a result, the field crew must try to maintain the elevation of the measuring tape from the back peg to the front peg and all the way to the cliff edge where the measurement will be made. This is made especially difficult in thicker vegetation and on windy days. A third pin can be used to temporarily mark the cliff edge from which the measurement can be made. Repeated measurements of this scenario by the field crew in 2015 led to differences as large as 0.10 m. Additional tests were conducted where several crew members each took measurements independently according to the field methodology to assess differences in edge interpretations. Results of these tests were encouraging and resulted in differences no greater than 0.10 m. It is the recommendation and experiences of this study that measurements taken according to the detailed methodology included an error of 0.20 m. Other coastal monitoring methods; airborne aerial imagery, airborne laser, terrestrial laser, terrestrial direct measurements with GPS have been seen to have errors 1 – 5 m, 0.2 – 1 m, 0.02 - 0.086 m, +/- 0.10 m respectively (Gulyaev and Buckeridge, 2004, Day et al, 2012). Note: an affordable laser measuring device may assist in reducing these errors, and should be tested.

2.4 Chapter 2 Concluding Remarks

Seventy-four (74) coastal erosion monitoring locations were measured between 2014 and 2015 with an average total loss of 0.46 m. Of the 74 locations, 34 were at historical monitoring locations and 40 were newly established in 2014. Twenty-four (24) more locations were added to the program in 2015 for a total of 98 measurements possible for the following field season.

This approach has shown that rates of coastal erosion vary across the Province with highest single year losses occurring at Naufrage light house, Seaview, and Governor's Island. It has been seen that 2014-2015 losses show no discernable bias to higher rates on either the north or south shores of Prince Edward Island as a combination of geomorphological processes including wave action, groundwater flow, surface run-off, and wind lead to variability. However, the short-term time frame of data collection does not allow for any conclusions to be made on long term erosion rates and the possible contributing factors due to the variability inherent in natural environments. Historical rates of erosion were calculated from original field notes and further iterate the variability in yearly measurements and location. Records show that attempts in the past were made to reestablish a monitoring program with limited effectiveness whereas this study was able to successfully re-establish many of the original sites and establish many new sites with wider provincial coverage. A comprehensive methodology has been developed and documented for the sustainability of the monitoring program and knowledge transfer. It is the recommendation of this study that an annual monitoring program continue for many years as a complement to other airborne and terrestrial monitoring methods on Prince Edward Island.

Although the results of this study cannot yet be used to quantify rates of erosion for understanding long-term trends representative of the total Island erosion, and the impact of environmental processes on rates because of the limited number of yearly measurements, this study has demonstrated the feasibility of a low cost approach to environmental coastal monitoring. A framework for long-term monitoring has been established and the continuation of the program has the potential to build on the knowledge of coastal environmental processes and help in the adaptation to climate change.

Future work will involve a comparison of peg line measurements to different methods for determining coastal change. Future modifications to the methods described could be made to include other types of coastal environments. Development of a web based platform for updating, visualizing, and communicating coastal data is also an area of interest. Although the focus of this paper was to demonstrate a simple, low cost approach, the affordability and practicality of emerging technologies should be investigated.

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Chapter 3

sUAS Comparative Analysis for the Application to Coastal Erosion Monitoring at North Lake, Prince Edward Island, Canada

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Target Journal: Geomorphology or Environmental Monitoring and Assessment

Abstract

The low operating cost and flexibility of sUAS enables the University of Prince Edward Island's Climate Research Lab to repeatedly survey study sites to investigate the impacts of individual storms on coastal change. The majority of damage along the coast of PEI occurs during storm events which are expected to increase in frequency and severity under climate change. This study completes a comparative analysis between a fixed wing and quadcopter unmanned aerial system in measuring coastal changes over time. The impact of using ground control points during image processing resulted in an average image marker to ground control point coordinates difference of 0.10 m and 0.03 m for the fixed wing and quadcopter respectively. Coastal delineation from orthomosaics compared to a ground truth coastal trace using survey grade global positioning system (GPS) resulted in an average difference of 0.25 m and 0.21 m for the fixed wing and quadcopter systems respectively. Elevation comparison of the resulting digital surface models to a ground truth GPS survey resulted in -0.117 m average difference for the fixed wing and 0.0224 m average difference for the quadcopter. Furthermore, consideration of cost, time, and ambient factors are addressed. Finally, sUAS technology is seen to have the potential to revolutionize the field of environmental monitoring in low capacity regions, building local knowledge capital for better planning and adapting to the impacts of climate change.

Acknowledgements

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3.1 Introduction

Climate change is expected to impact coastal areas around the world through increased storm severity and frequency. Sea level rise is expected to exacerbate the vulnerability of coastal land to flooding and storm surges by increasing the influence of water inland. Coastal areas have a long history as an economic driver, originally, driven by the fishing industry and more recently through development and tourism. Not to be forgotten is the high environmental value of coastal zones at risk to the adverse effects of climate change. As a result, there is a need to better understand and document the geomorphological processes of the coastal zone for improved adaptation. Coastal monitoring over a range of temporal and spatial scales has been recognized by the Intergovernmental Panel on Climate Change (IPCC) as an important aspect to understanding the effects of climate change (Nicholls and Cazenave, 2010).

Study of coastal geomorphology increasingly relies on high spatial resolution and vertically accurate Digital Surface Models (DSM) to reconstruct the three-dimensional environment to reliably simulate coastal erosion, flooding phenomena, and assess the coastal sediment budget (Mancini et al, 2013). The emerging industry and field of study surrounding small Unmanned Aerial Systems (sUAS) has made it possible to study environmental processes and changes at spatial and temporal scales that would be difficult or impossible using traditional remote sensing techniques (Whitehead et al., 2014). Application of conventional remote sensing platforms can be limited by cost, resolution, and flexibility whereas sUAS are often particularly well-suited (Whitehead et al, 2014).

Coastal monitoring requires successive data collection from which change can be detected and analyzed. Traditional data collection methods can include measurement of peg-lines (Irvine, 2014), or comparison of aerial imagery for erosion rates (Webster et al, 2012); reconstruction of the coastal zone through Global Navigation Satellite System (GNSS) surveys (Baptista et al, 2007, Harley et al, 2010), total station and Terrestrial Laser Scanning (TLS) (Mancini, 2012), or airborne LiDAR (Light Detection and Ranging). Each of these data collection methods provide the capability to delineate coastal indicator features for monitoring coastal erosion with varying degrees of accuracy and limitations. Peg-line measurements are easily repeatable and established but are limited by the amount and type of resulting data, that is, sparse erosional point data (Gulyaev and Buckeridge, 2004). Temporal comparison of orthorectified aerial photos provides a means of coastal erosion monitoring by delineating the coastline over several years to resolve a rate of change (Webster et al, 2012). Generally, this method is limited by the existence of high resolution aerial photos or satellite imagery captured for purposes other than coastal monitoring. Traditional methods of high resolution data acquisition tend to come with a high cost and will make it difficult to support annual long-term monitoring. GNSS surveys are fast and accurate but limited in the number of measureable points and coverage that can be limited by terrain. TLS requires significant survey and data processing time, although can be very accurate. Airborne LiDAR provides the ability to investigate extensive areas but is costly and does not produce spatial and vertical accuracies comparable to GNSS and TLS (Mancini et al, 2013).

Recent developments in a new generation of image matching algorithms coupled with sensor miniaturization, and improved battery technology has led to the application of Unmanned Aerial Vehicles (UAV) across a wide range of disciplines (Harwin and Lucieer, 2012). UAV have been used in coastal areas to map river channels (Flener et al, 2013), generate DSM (digital surface model) of a beach dune system (Mancini et al, 2013), and investigation of aeolian sand dune formation and evolution (Hugenholtz et al, 2011). Application to environmental sciences stands to benefit greatly from the versatility of UAV technology, particularly where remote sensing data is required. Small Unmanned Aerial Vehicles (sUAS) have been used to monitor the woodlands of Poland (Zmarz, 2013), monitor Himalayan glacier dynamics (Immerzeel et al, 2014), and have been seen as a revolutionary tool for studying spatial ecology (Anderson and Gaston, 2013). With increased application comes a need to validate the data generated by sUAS in different environments with varying parametres. This work concentrates on coastal environments. A common form of validation is through the use of ground control points or site survey using real time kinematic (RTK) GPS (Harwin and Lucieer, 2012, Mancini et al, 2013, Flener et al, 2013, Hugenholtz et al, 2013). Accuracies can also be quantified by comparing against existing aerial imagery and elevation models with known accuracies (Douterloigne et al, 2010, Flener et al, 2013, Westoby et al, 2012, Strecha et al, 2012).

UAVs have become less expensive and easier to operate and provide coastal researchers with a tool that overcomes many of the limitations of traditional data collection methods; in particular, cost as well as spatial and temporal resolutions. Consequently, this chapter constitutes a comparative analysis between two sUAS in the application to coastal monitoring of cliff and bluff environments on the north shore of Prince Edward Island, Canada. The systems utilized in this study were a fixed wing UAV – PrecisionHawk's Lancaster Rev 3 and a quadcopter UAV – 3DRobotics Iris+ Mapper. This chapter seeks to evaluate and compare the accuracies of the orthomosaics and DSM generated from aerial imagery processed using Pix4D software. Elevation accuracies are assessed by comparing to a network-based differential GPS (DGPS) survey of the study site and 2008 airborne LiDAR survey. Coastline delineation of the UAV orthomosaics will be validated by comparing to a ground truth DGPS trace of the cliff/bluff top edge. Subsequent surveys of the study area followed by cliff/bluff top coastal delineation will serve as the method by which coastal erosion rates in this type of environment can be monitored. Ground control points (GCP) were distributed throughout the study area before each system's survey and were used during data processing to improve results. Also included in this study is a comparison of the impact GCP have on georeferencing of the UAV data, keeping in mind that setting up GCP is the most time consuming aspect of these surveys which will in turn affect the extensiveness of a coastal monitoring program possibly using the methodology outlined in this paper.

Validation of the three dimensional (3D) surface products is necessary to provide confidence in tertiary products where the UAV generated DSM are used as input data for numerical models such as storm surge models, flooding models, or sediment budget models. Furthermore, accurate coastal delineation will provide the methodological approach to the establishment of an extensive coastal erosion monitoring program at the local scale where erosion rates can be confidently resolved and used by decision makers to improve regulations and ecological protection.

3.2 Methods

3.2.1 Study Area

The comparative analysis completed for this study concerns a 300 m stretch of cliff along a section of open coast on the north eastern tip of Prince Edward Island; Canada's smallest province located in the Gulf of St. Lawrence. The study area, North Lake, is contained within the Naufrage coastal compartment and has a northern exposure. The cliff top ranges from 7.0 m – 10.5 m in elevation and has a rocky base. The survey extends between 100 m - 170 m back from the cliff edge. The landward side of the cliff top is mostly free of tall vegetation with high point of about 16 m in the South West corner of the survey area sloping away to a low point of 7 m in the North West and South East corners of the survey area.

The study area has seen an average rate of erosion of 0.29 m between 1968 and 2010 where aerial photos were compared to obtain historical rates of erosion (Webster, 2012). This area was chosen because its average rate of erosion closely matches the average rate of erosion for the entire Province which was calculated by Webster to be 0.28 m. Also, the lack of vegetation on the backshore was anticipated to lead to a more "bare earth" DSM for better comparison with the GNSS survey and existing LiDAR Digital Elevation Model (DEM). The study area represents a very typical cliff or bluff environment that might have a house or cottage on the property with concerns of a retreating coastline.

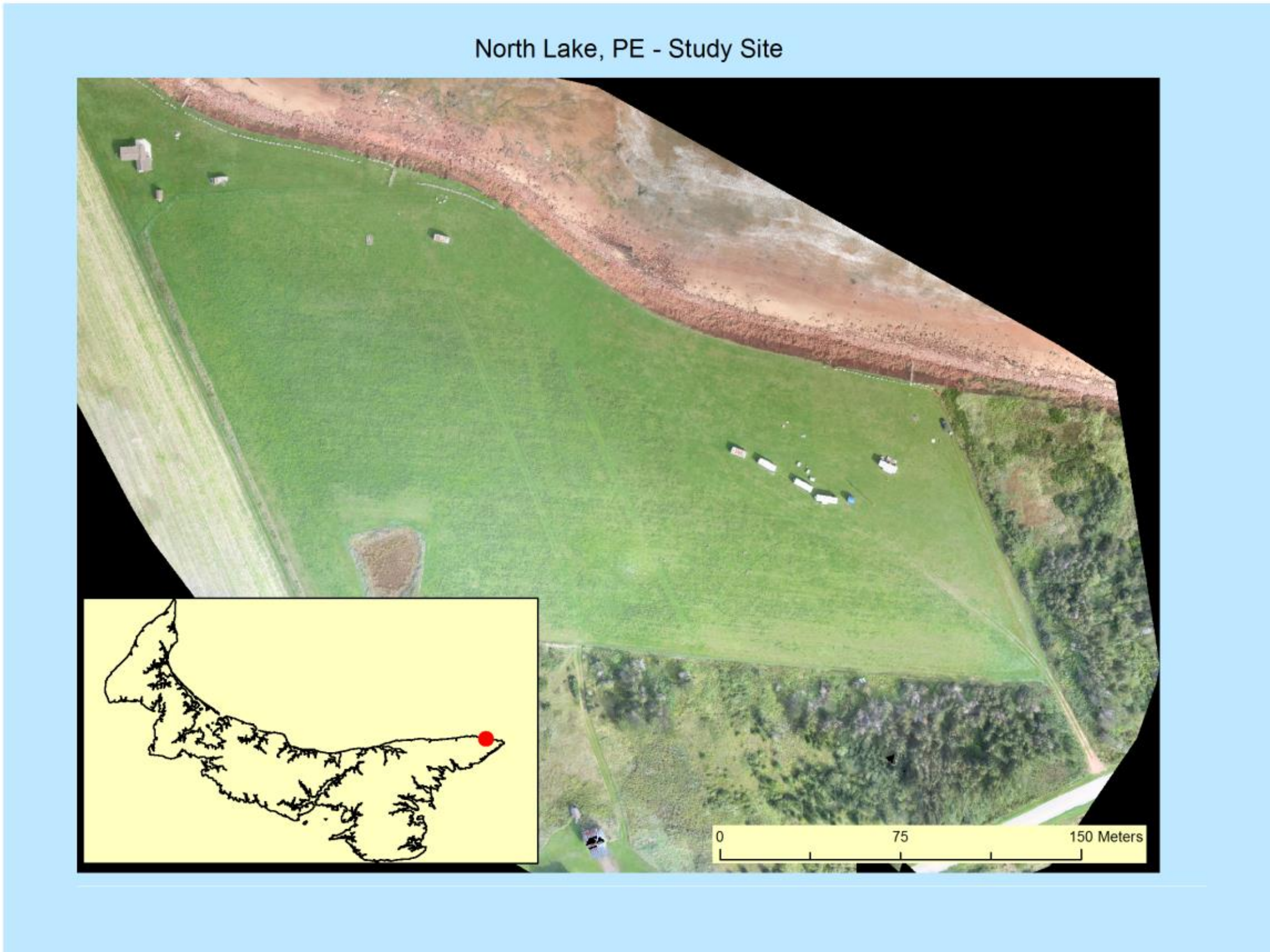

Figure 21: North Lake, PE - Study Site.

3.2.2 Global Positioning System (GPS) Elevation and Cliff Edge Surveys

A complete survey of the study area was completed on September 23, 2015 using a dual frequency receiver, Trimble Geo7x, connected to a Networked Real Time Kinematic (NRTK) correction service. The study area was surveyed by walking with the GPS receiver and antenna attached to a 2.0 m pole in roughly 10-15 m transects with attention to maintain a constant elevation above the ground and verticality of the pole as directed by a spirit level. In total, 3,650 data points were collected over the hour long survey of the landward side of the cliff top and cliff base with horizontal precision of 0.024 m and vertical precision of 0.035 m with 95% confidence determined by Trimble Pathfinder Office correction software. Although some human error can be introduced by the positioning of the GPS receiver, this set of points is considered the elevation ground truth from which all elevation models will be compared against.

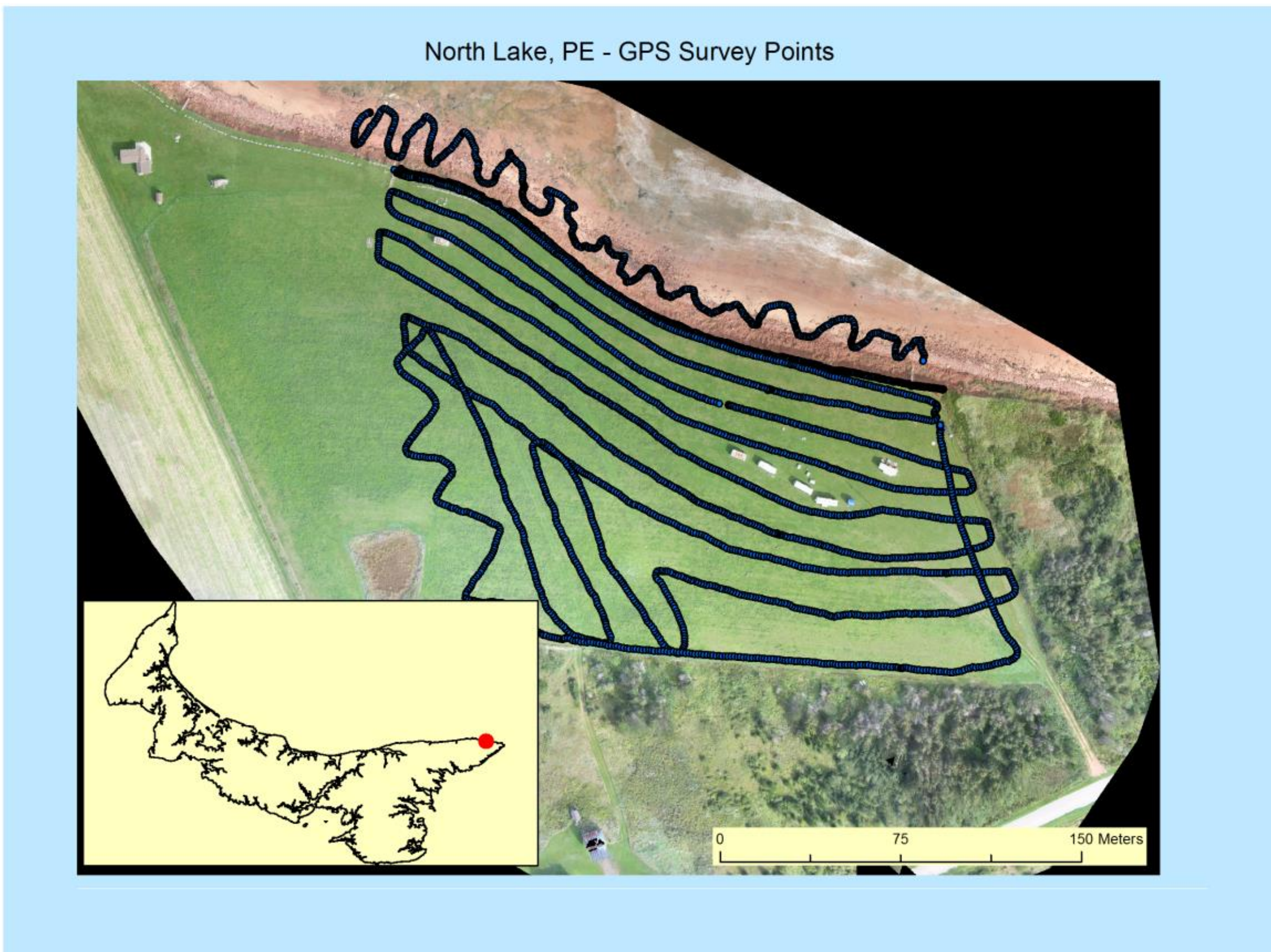

Figure 22: GPS Survey Points. 3,650 elevation points with a high confidence in accuracy includes elevations at the base of the cliff and the entire survey area of interest in the back shore. Points are used to sample elevations of a LiDAR DEM and UAV DSM.

Following the GPS survey of the study site, a trace of the 250 m length of the cliff edge was completed with the same equipment and attention to receiver position. The cliff top edge trace resulted in a line connecting 703 data points with horizontal precision of 0.024 m and vertical precision of 0.035 m with 95% confidence. Measurements were taken from the most seaward edge of the cliff top, to the best of the operator's ability, even for areas where there was cliff top slumping or cracking. This was to maintain consistent coastline delineation with the UAV surveys where slumping and cracking cannot be identified from the orthomosaic. The cliff top edge tracing is used to validate spatial accuracy of the UAV surveys for how well the location of cliff edge can be represented in mapping software.

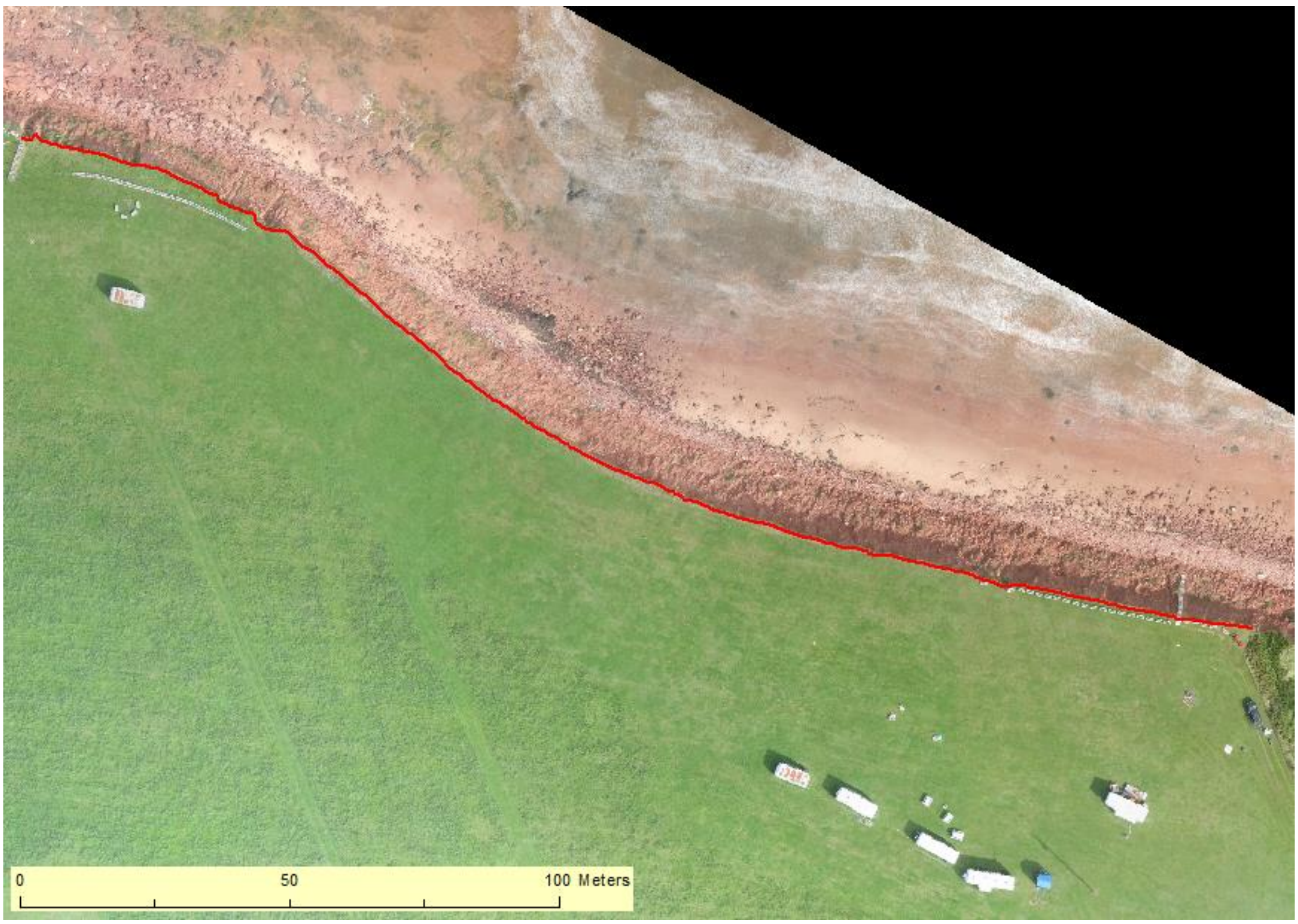

Figure 23: Global positioning system (GPS) coastal trace overlaid on a UAV orthomosaic of the study site.

Horizontal coordinates were referenced to WGS 1984 UTM Zone 20N (Natural Resources Canada, 2016) while the vertical values were referenced to mean sea level using the Canadian HT2_0 Geoid Model.

3.2.3 The Light Detection and Ranging (LiDAR) Data

Complementary to the NRTK global positioning system (GPS) elevation survey, a 2007 LiDAR Digital Elelvation Model (DEM) was used to validate elevations of the landward portion of the study area. The cliff base was not included as it is expected to have changed due to wave action. The government of Prince Edward Island acquired the LiDAR data for the entire province at a cost of $880,000 CAD (McCourt, 2009). The LiDAR DEM dataset has a spatial resolution of 1.5 m and vertical accuracy of 0.15 – 0.30 m. Elevations are represented by orthometric heights above the geoid, mean sea level, using the Canadian HT2 Geoid Model. The LiDAR DEM was validated by Webster et al (2010) using high precision survey monuments and RTK GPS.

3.2.4 The small Unmanned Aerial Systems: Fixed wing & Quadcopter

Two small Unmanned Aerial Systems were used; PrecisionHawk's Lancaster Rev 3 fixed wing UAV, and 3DRobotics Iris+ Mapper VTOL (Vertical Takeoff and Landing) quadcopter. Detailed specifications of the systems can be found in Table 2.

	Fixed Wing: PrecisionHawk Lancaster Rev 3	Quadcopter: 3DRobotics Iris+ Mapper
Weight	Airframe: 1.7 kg Battery: 0.34kg Payload: .8 kg	1.5 kg including battery and payload
Measurements	Wingspan: 1.5 m Length: 1 m	0.55 m diagonally
Battery	3900 mAh lithium-polymer	5100 mAh lithium-polymer
Flight Time	15 minutes	15 minutes
Payload	RGB: Converted Nikon J3 14.2 MP	RGB: Canon S110 12 MP
Resolution	1.3 cm/pixel	3.1 cm/pixel
Takeoff/Landing	Hand launched/belly landing	Vertical takeoff and landing (VTOL)
Cost	$41,000	$4,500

Table 2: UAV specifications.

Flights were conducted on September 25, 2015 and October 5, 2015 for the quadcopter and fixed wing systems respectively. Attempts were made on the first day to fly the fixed wing but had to be abandoned due to wind conditions. Imagery for both flights was acquired at an altitude of 90 m above ground level. Ground control points (five (5) – fixed wing, six (6) - quadcopter) were distributed throughout the survey area before each flight and measured with the GPS set-up detail previously to centimetre accuracy. A reduced number of GCP were used compared to similar validations in the literature (Harwin and Lucieer, 2012, Mancini et al, 2013). This was done because of the intended application to coastal monitoring of many study sites. Four (4) GCPs are sufficient to negate the GPS biasing effect and accurately georeference a survey (Douterloigne et al, 2010). Additional GCPs were used in this work to increase the likelihood of accurately representing the coastal indicator feature of interest. Five to six (5-6) GCPs were used with GCPs placed near each corner and middle of a roughly square survey. In general, additional GCP setup tends to increase field time and will require additional GCPs to target manual selection prior to image processing. An emphasis on efficiency is necessary for successful long-term monitoring of many sites.

Quadcopter

Survey lines were planned during the 'flight planning' stage using open source software known as Mission Planner by creating a waypoint file. Six (6) flight lines or transects were used to cover the roughly 10 acre study site with a 70% side and end overlap. Flight operations are nearly fully automated only requiring the field crew to maintain visual line of site with the vehicle and monitor mission vitals like telemetry strength and battery until landing where minimal user input can improve landing accuracy. Conditions were sunny with 20 km/h sustained South East winds with gusts up to 40 km/h according to Environment Canada on September 25, 2016. The quadcopter performed beyond reasonable expectations on this windy day, deviating only slightly horizontally and vertical deviations up to 2 m. Total flight time was eight minutes at an average speed of 6.5 m/s. The resulting dataset was 87 geotagged images.

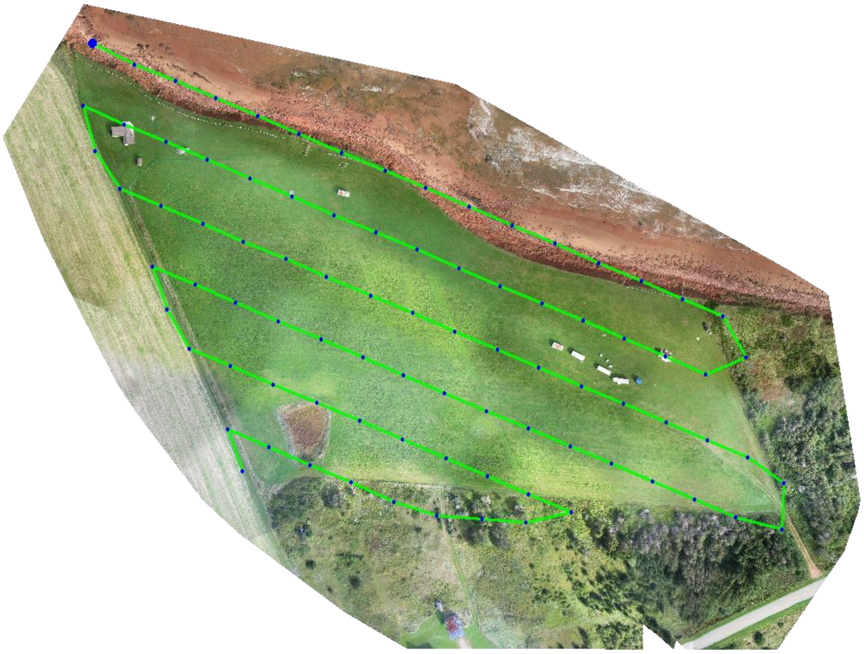

Figure 24: Image positions and flight lines of the quadcopter UAV flight generated by the Pix4D quality report.

Fixed Wing

The survey using the fixed wing vehicle took place some days later when wind conditions were more favourable. Flight planning is completed in proprietary software where the user simply chooses the area of interest of the survey with image overlap; 70% side and end overlap in this case. In this case, the survey was constructed to include the coastal area of interest. The vehicle was hand launched; thereafter it automatically flew to the center of the area of interest at the desired altitude. The aircraft will then conducts a loiter where it calculated the best way to complete the predetermined survey based largely on wind direction. Following the loiter, 16 flight lines were needed to complete the survey in 10 km/h Southerly winds. Flights lines corresponded to either a head wind or tail wind which greatly affected the ground speed of the aircraft, ranging from 2 m/s in a head wind to 20 m/s with a tailwind. A total of 526 images were taken, 492 of which were successfully geotagged. Total flight time was 12 minutes with major deviations horizontally and vertically (-7 m - +3 m) along the flight lines.

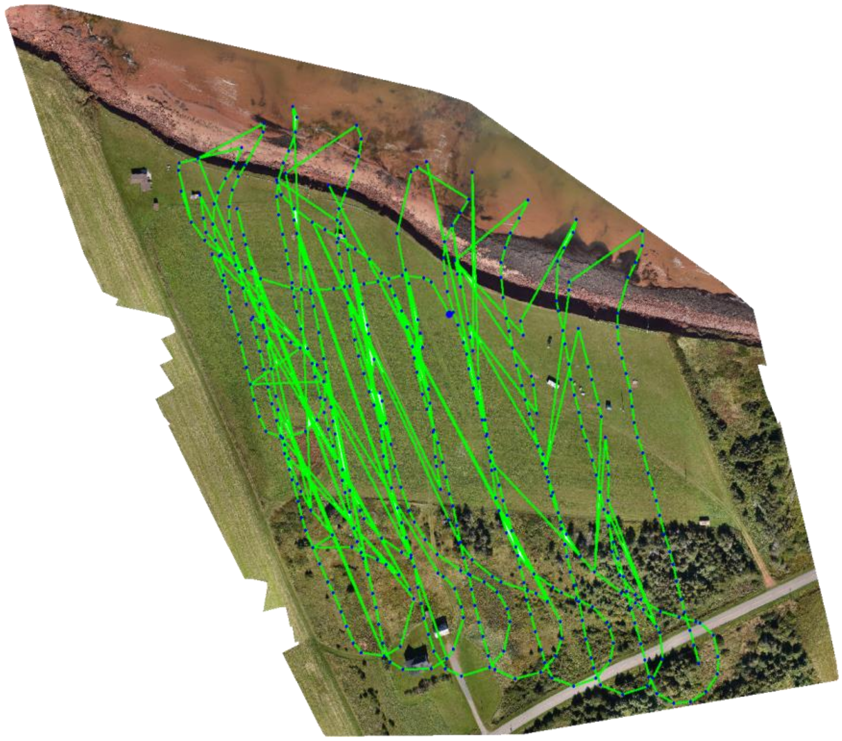

Figure 25: Image positions and flight lines of the fixed wing UAV flight. Flight lines are parallel to wind direction. Considerably more flight lines and images are needed to complete the same survey as the quadcopter.

This particular fixed wing performs a belly landing and generally requires the pilot in command to make it as smooth as possible. Good practice with a fixed wing is to land into a head wind. This system reduces its altitude to 30 m and comes into a preset landing location from 250 m out. Fail-safes exist in case of an emergency; otherwise the pilot-in-command will take manual control of the aircraft in the final stages of the landing to ensure the nose is up and avoid any obstacles.

3.2.5 Data Processing and Analysis

Data processing of the UAV imagery was completed using an educational license of Pix4Dmapper Pro software. Pix4D is a professional image-processing software commonly used in industry and research. Pix4D image processing automatically finds thousands of common points between images known as *key points*. A *matched key* point is when a key point is found in two images. A 3D point will be generated from correctly matched key points. More key points will result in more accurate 3D points so high image overlap is required (Pix4D Mapper Manual, 2015). Pix4D was used to create high resolution (0.035 m/pixel) orthomasaics and digital surface models (DSM) datasets from the fixed wing and quadcopter imagery on which the analysis was conducted.

Two datasets were created for each of the UAV platforms - one processed using ground control points and one processed without the use of ground control points, using only the geotagged imagery from each vehicle's on-board global positioning system (GPS). From a long-term monitoring perspective, the impact of GCP on data accuracy was of interest. In total, four datasets were created to compare against each other and the ground truth datasets.

All data was brought into ArcGIS mapping software. Data included; four (4) UAV orthomosaics, four UAV Digital Surface Models, LiDAR Digitial Elevation Model clipped to the study area, GPS survey point shapefile, two (2) GPS Ground Control Point shapefiles, and GPS cliff top edge trace. The cliff top edge was digitized from each orthomosaic to create four (4) new coastline shapefiles for comparison against the ground truth GPS coastal trace. Note: The coastline from 2010 as digitized from 0.40 m orthorectified aerial photos was also included in the comparison as an exercise for calculating a rate of erosion between 2010 and 2015. Thirty (30) transects were created perpendicular to the ground truth coastline at 10 m increments along the length of the line. Points were created at each intersection of the transect lines with a coastline. Using the Point Distance Analysis Tool with a search radius of 7 m, point distances along each transect line were calculated as the absolute difference from the ground truth point along the corresponding transect line. This quantifies the accuracy of using UAVs to delineate and identifies the position of the coastline and the applicability to a long-term monitoring program.

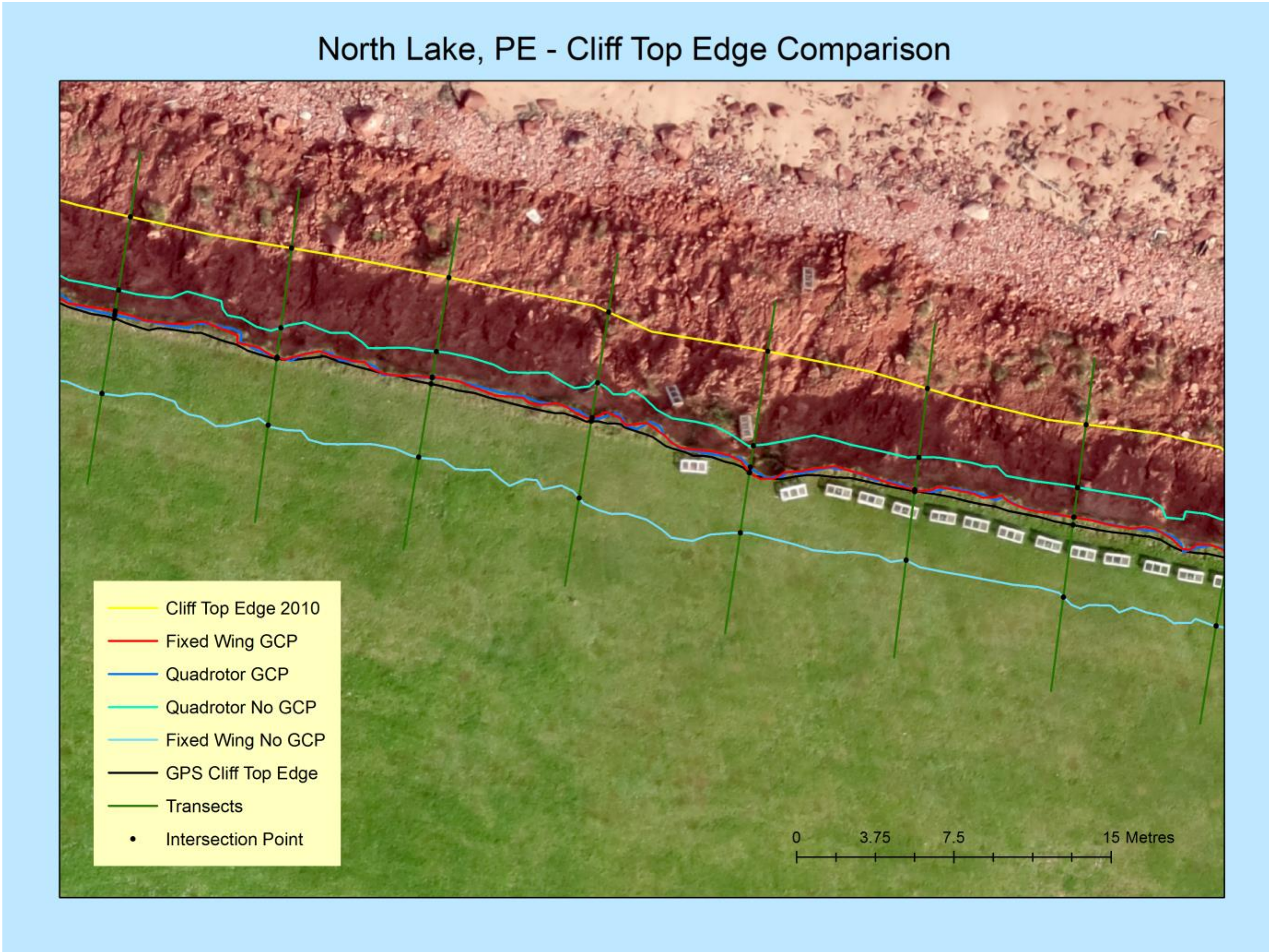

Figure 26: Coastal delineations of all UAV datasets, ground truth coastal trace, 2010 coastline delineation. Transect lines were created perpendicular to the ground truth coastal trace. Points were created at each intersection of a transect line and coastline. Distances between points were calculated against the ground truth intersection points.

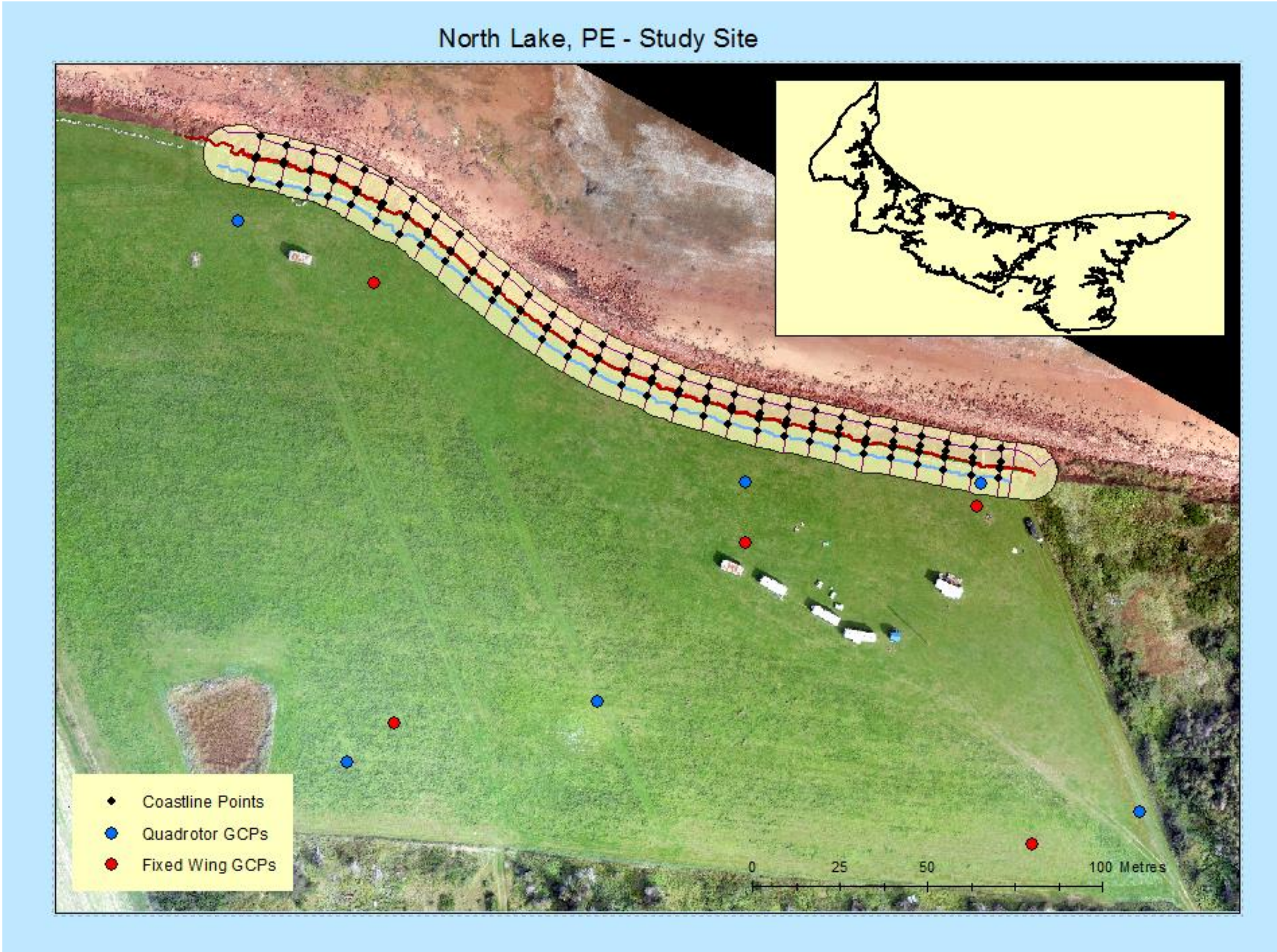

Figure 27: Study site with GCP marked by blue and red points. Transect lines and coastlines show the 300 m length of coastline used for validation.

Spatial accuracy was also quantified by comparing the positions of the GCP markers seen on the orthomosaics to the GCP shapefile collected using NRTK GPS. Figure 28 demonstrates the result of using ground control points during image processing on overall geolocation.

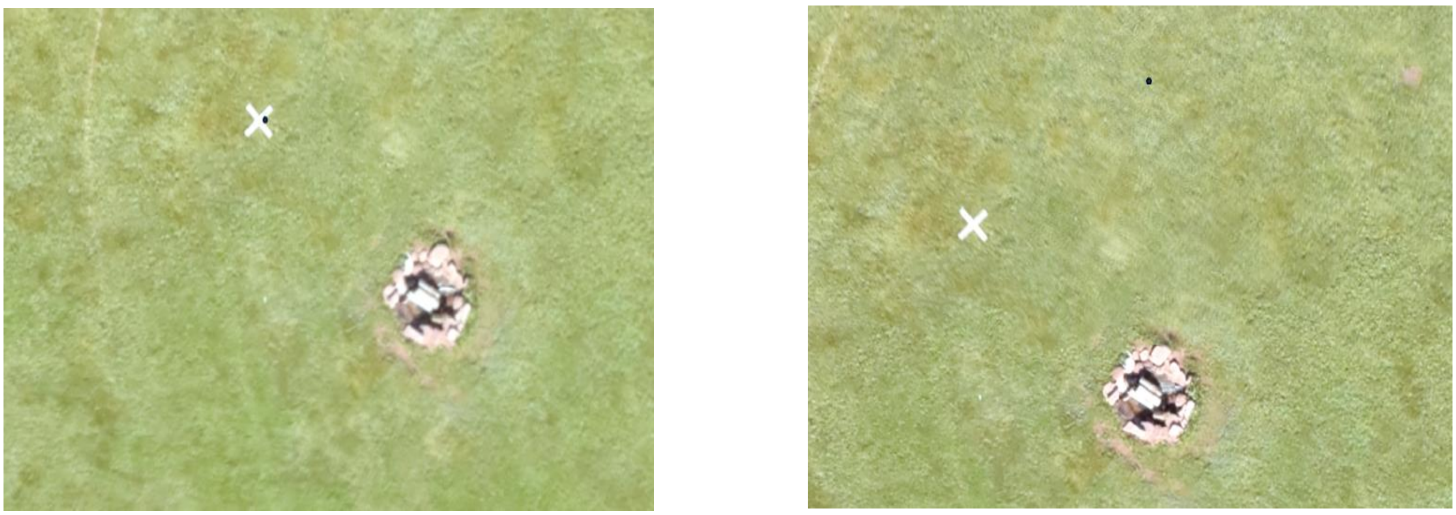

Figure 28: Othomosaic generated with GCP (left) shows the GCP marker (white X) matches very closely to the GCP coordinates (black dot) of that marker. Orthomosaic generated without GCP (right) shows a considerable difference between GCP marker and GCP coordinates.

Vertical accuracy was quantified by sampling the points in Figure 2 from the GPS survey against each DSM and the LiDAR DEM using Extract Multi Values to Points Spatial Analyst Tool. This tool extracts the cell values at locations specified by an input point feature class (GPS survey point shapefile) from one or more raster files (DSM) and records the values in a table corresponding to the sampling point. With this information, difference in elevations can be compared against the ground truth survey to quantify the accuracy and plot the trends.

3.3 Results and Discussions

3.3.1 Image Processing (Fixed Wing & Quadcopter)

Quadcopter

Eighty-seven (87) calibrated images of 87 geolocated images were used in initial processing with an average ground sampling distance of 3.07 cm, adjusted to 3.5 cm for a consistent ground sampling distance across all datasets. The output coordinate system used for the 0.1006 km^2 area was WGS 1984 UTM Zone 20N (Natural Resources Canada, 2016). Over 7.5 million (7,725,999) 3D densified points were created from an average of 12,217 matched 2D key points per image. Total automatic processing time for each dataset (with and without GCP) was about 1 hour with about 45 extra minutes during project set up to incorporate the GCP. The resulting file sizes were in 440 MB and 521 MB for the orthomosaic and DSM respectively.

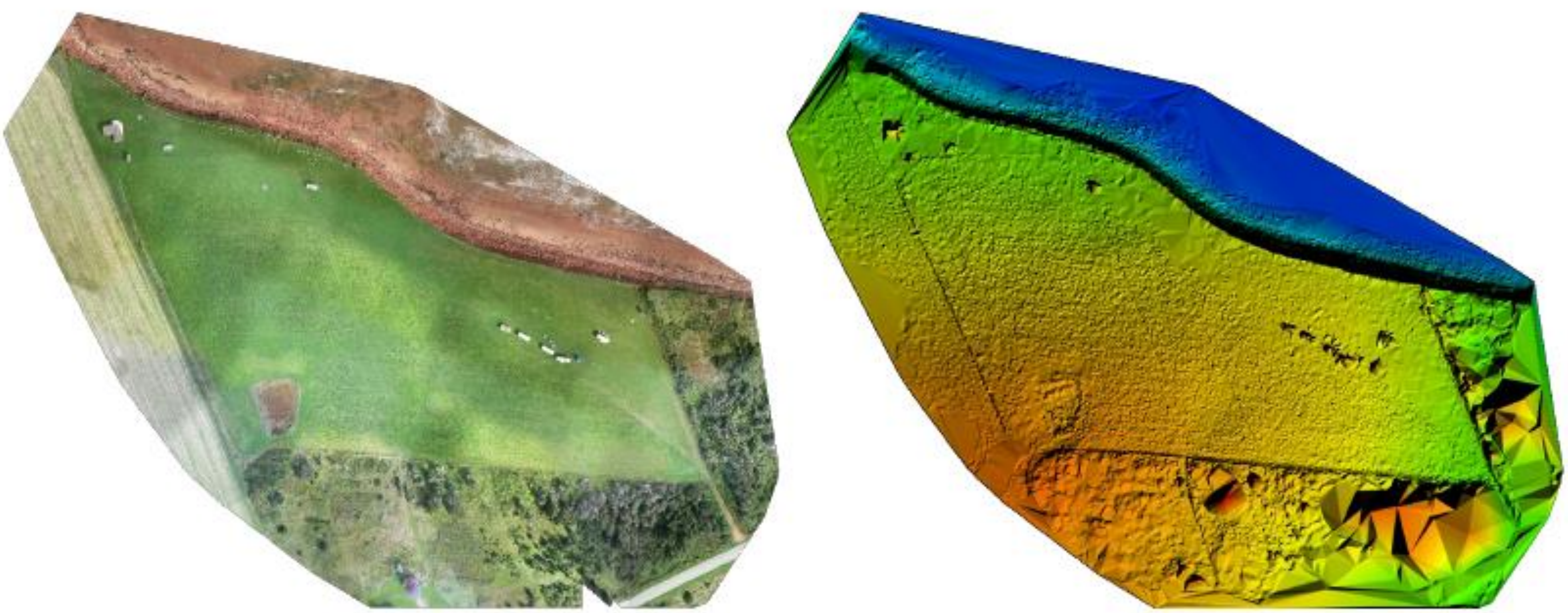

Figure 29: Quadcopter orthomosaic and corresponding sparse DSM before densification.

Fixed Wing

Four hundred eighty-six (486) calibrated images of 526 geolocated images were used in initial processing with an average ground sampling distance of 1.33 cm, adjusted to 3.5 cm for a consistent ground sampling distance across all datasets. Output coordinate system used for the 0.1614 km^2 area was WGS 1984 UTM Zone 20N. 86,994,970 3D densified points were created from an average of 9,124 matched 2D key points per image. Total automatic processing time for each dataset (with and without GCP) was well over 5 hours with about 45 extra minutes during project set up to incorporate the GCP. The resulting file sizes were 606 MB and 765 MB for the orthomosaic and DSM repectively.

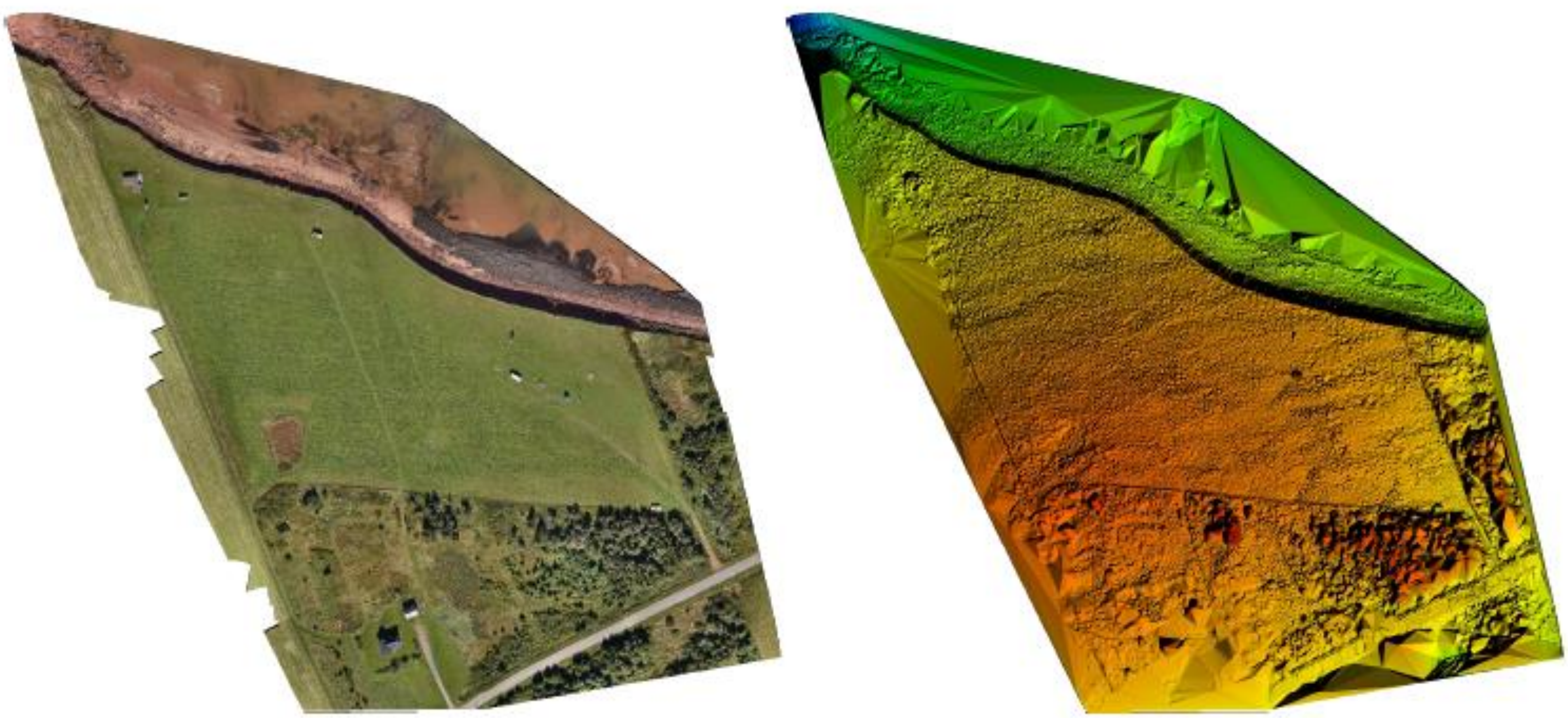

Figure 30: Fixed wing orthomosaic and corresponding sparse DSM before densification.

Of particular note during the processing of the UAV imagery is the difference in the number of images captured for basically the same area; 526 for the fixed wing platform and 87 for the quadcopter platform. The number of images processed will greatly affect the total processing time and data size on disk. Larger file size will also lead to slower performance and rendering during analysis. The number of images captured during flight is related to the number of flight lines. The quadcopter UAV conducts a much more efficient survey with fewer flight lines for the same area as a fixed wing vehicle. A fixed wing vehicle will have to perform loops outside the survey area to turn around and will capture fewer images on a downwind flight line than an upwind flight line which is compensated by increasing the number of flight lines. These are important considerations when evaluating a data-capturing platform's applicability to long-term monitoring of the coast where efficiency is crucial.

3.3.2 Spatial Influence of Ground Control Points

Figure 31 summarizes the results for the two systems used in this study where five (5) GCP were used for the fixed wing vehicle's flight and six (6) for the quadcopter. The average distance from the actual GPS coordinates to the respective GCP markers as seen on the processed imagery resulted in 3.50 m for the fixed wing without GCP, 1.40 m for the quadcopter without GCP, and 0.10 m and 0.03 m for the fixed wing and quadcopter with GCP respectively.

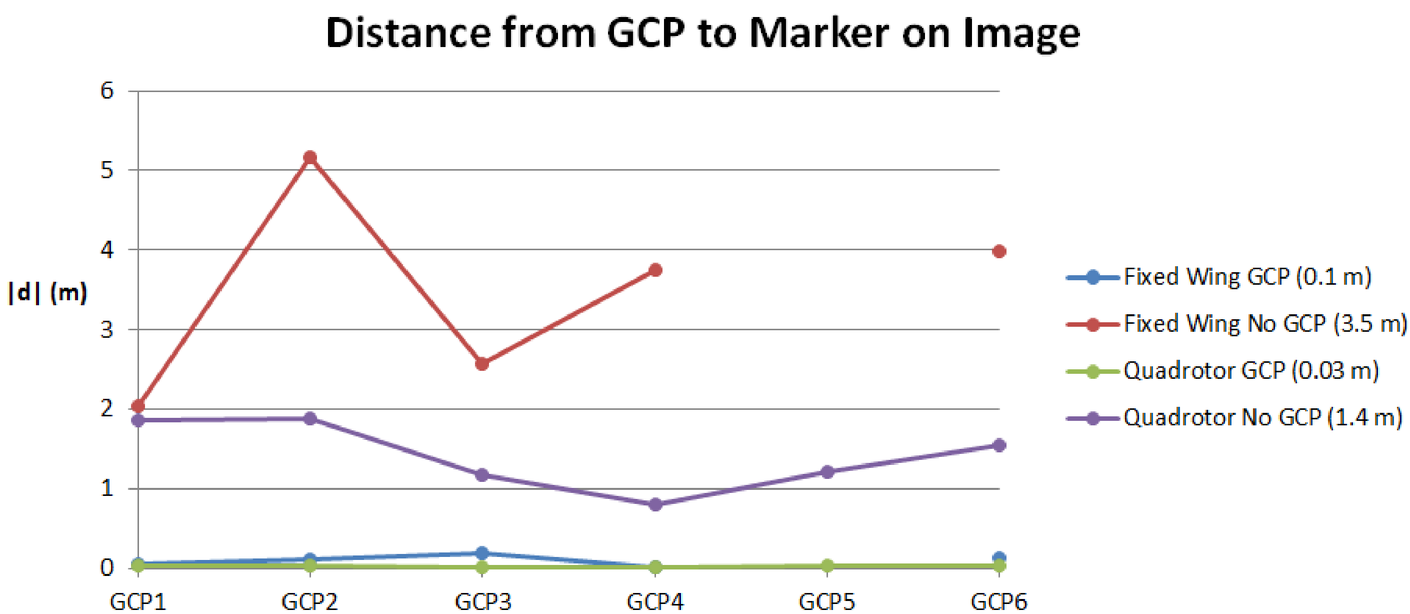

Figure 31: Distance of GCP markers to GCP coordinates of all datasets. 5 GCP were used for the fixed wing flight where 6 were used for the quadcopter flight.

The data here suggests that using GCP during processing has a great impact on the accurate georeferencing of the imagery, although there is a noticeable difference in the georeferencing between the fixed wing and quadcopter when only the geotagged images were used from the onboard GPS. The quadcopter does a reasonably good job georeferencing the data with no single GCP being more than 2 m away from the marker; however, the fixed wing is at best 2 m from a marker and at worst over 5 m from a marker. When focusing only on the imagery processed using ground control points for the fixed wing and quadcopter systems, a similar trend presents itself as shown in Figure 32.

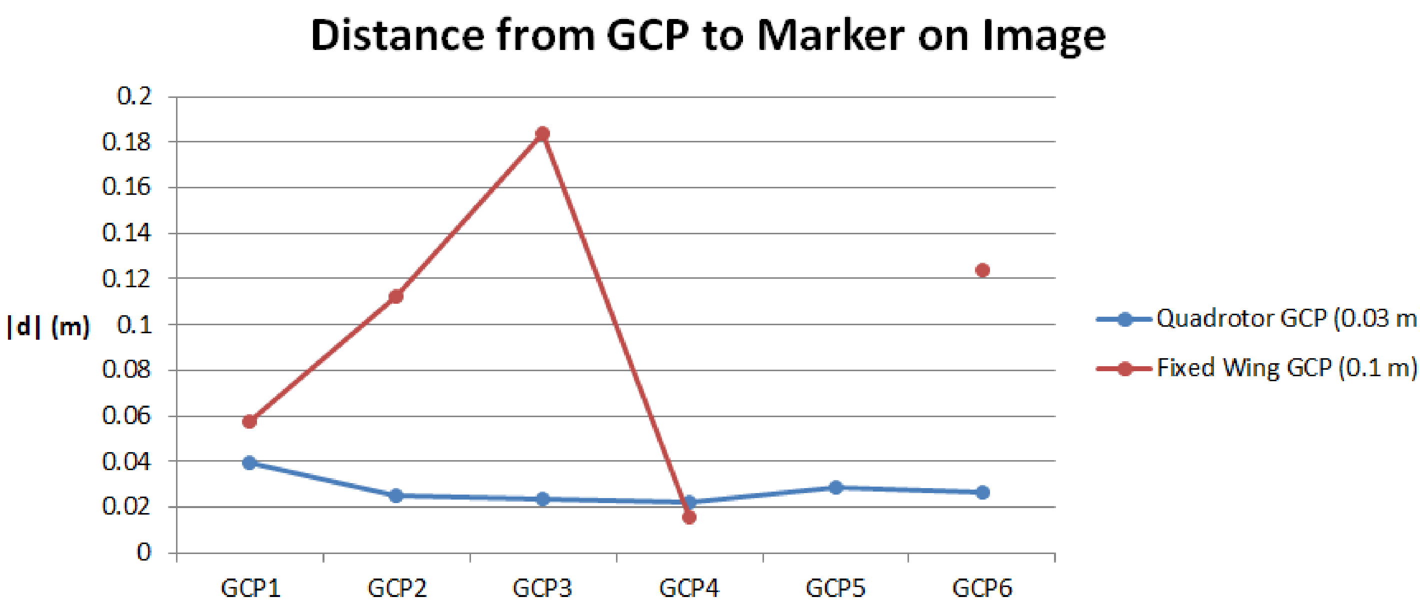

Figure 32: Distance of GCP markers to GCP coordinates of only the datasets processed using GCP. Quadcopter has an average difference of 0.03 m where the fixed wing has an average difference of 0.10 m.

Again, the quadcopter is out performing the fixed wing in the reliability of the georeferenced data. The quadcopter maintains a similar difference across all GCP in the centimetre range whereas the fixed wing has varying differences ranging from centimetres to decimetres.

3.3.3 Coastline Delineation

Figure 33 shows the absolute difference from the ground truth GPC coastal trace along 30 transect lines to each of the delineated coastlines. Included is the average over all transects for each dataset. In descending order of proximity in metres results in the 2010 coastline at 5.15 m, fixed wing without GCP processing at 3.9 m, quadcopter without GCP processing at 0.9 m, fixed wing with GCP processing at 0.25 m, and quadcopter with GCP processing at 0.21 m.

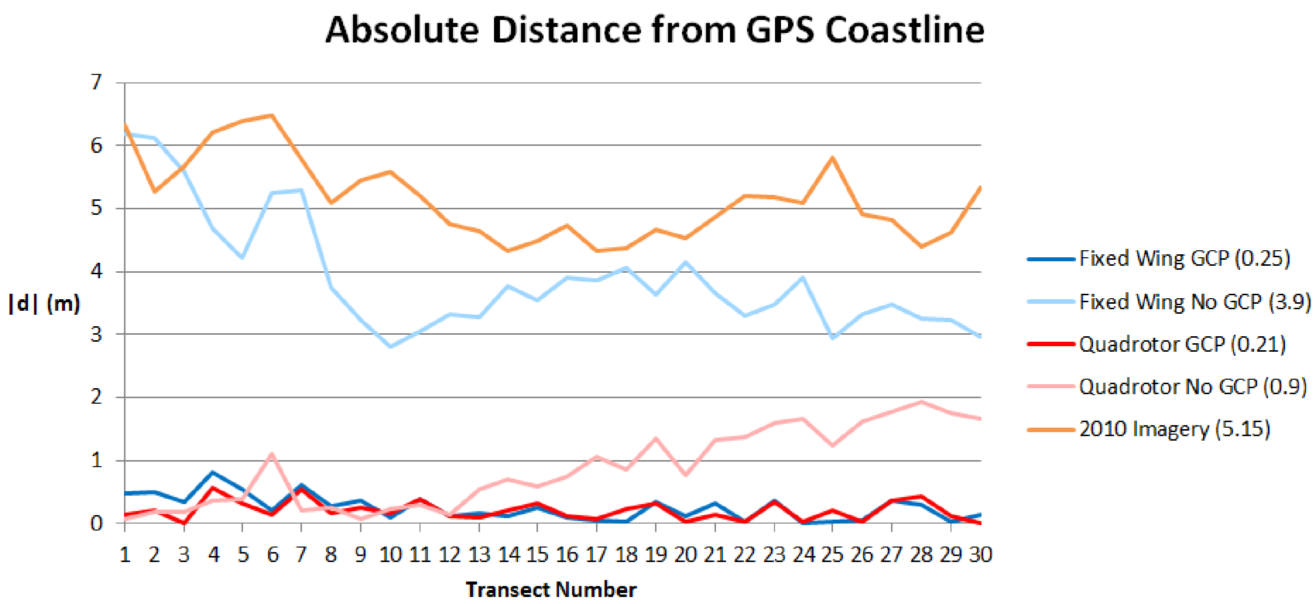

Figure 33: Coastal delineation difference to the ground truth GPS coastal trace.

A similar yet unsurprising trend appears again for the spatial accuracy of the coastal delineation. GCP are necessary to bring the coastline differences to the scale of annual erosion as seen in Figure 33 by the fixed wing and quadcopter GCP georeferencing. Similarly, the fixed wing with geotagged images alone is well out of the acceptable range. Interestingly, the quadcopter with geotagged images only matches the coastline reasonably well up to around transect 15 where the digitized coastline begins to veer away from the ground truth coastline. Investigating further, Figure 34 highlights the best matching coastlines.

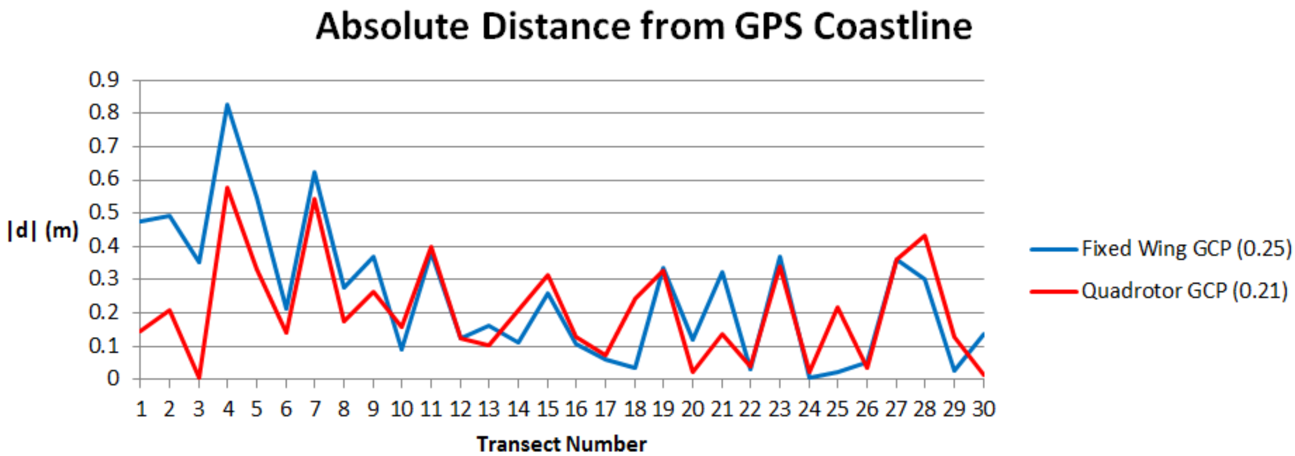

Figure 34: Coastal delineation differences from GPS coastal trace for the fixed wing and quadcopter dataset processed using GCP. An average difference of 0.25 m is observed for the fixed wing and 0.21 m difference for the quadcopter.

Both platforms do a good job matching the delineated coastlines to the ground truth coastline. The quadcopter appears to be slightly more accurate but the 0.04 m difference is too close for this not to be a result of human error during hand digitization of the coastline. The range in differences is of potential concern when trying to detect annual changes in that same range (0.28 m/year); however, this can be reconciled by the inherent differences in the data collection methods between the ground truth coastline and airborne imagery. When taking terrestrial measurements of the cliff top edge it is difficult to trace the exact edge of visible vegetation due to safety reasons and concern of keeping the antenna vertical. In contrast, it is very easy to delineate the exact edge from high resolution aerial imagery. In fact, for all transect intersection points, the ground truth points are on the landward side of the two coastlines in question; suggesting the edge of the cliff top was not traced exactly using the GPS which is consistent with the lead investigator’s experience in the field. As a result, UAV delineation of the coastline can be accurately used to monitor cliff top erosion if the same method is used over time.

Furthermore, a rate of erosion between 2010 and 2015 was calculated using transect intersection points of the 2010 coastline and 2015 fixed wing coastline (see Figure 35). The 2010 aerial imagery was not georeferenced as accurately as the UAV imagery so an offset was determined using the center road line that appeared in the 2010 imagery and only the fixed wing imagery. An offset of 1.4 m was found and applied resulting in 0.28 m/year erosion over 5 years. This is consistent with other methods of calculating coastal erosion in this area (Webster, 2012).

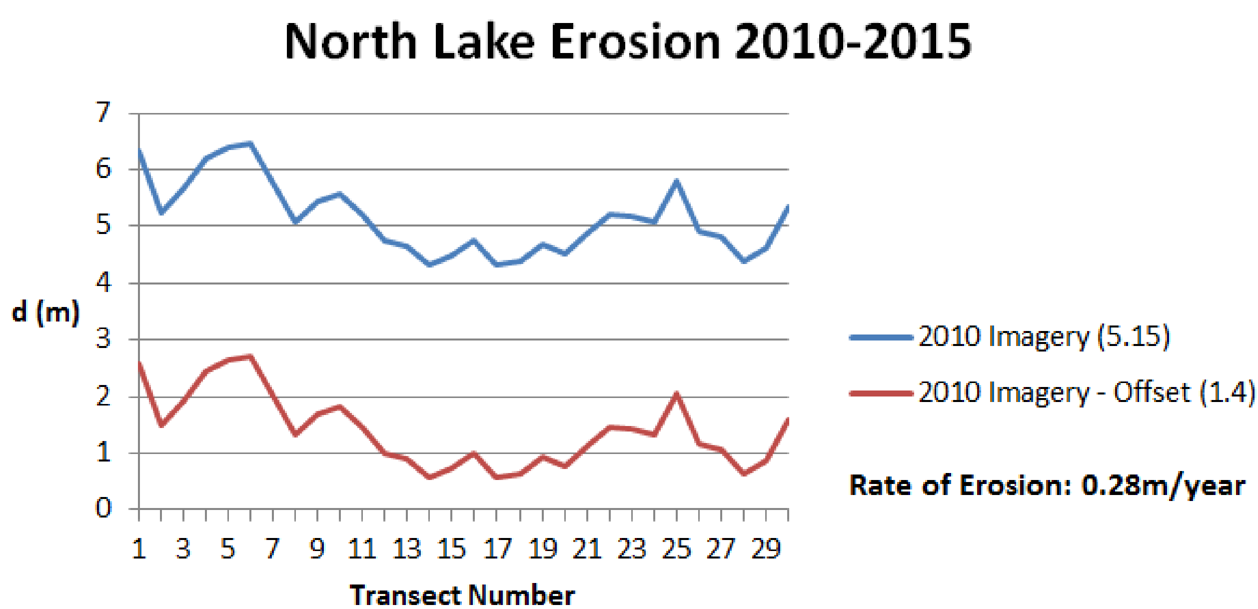

Figure 35: Erosion calculation between 2010 and 2015 using fixed wing imagery process with GCP compared against 2010 aerial imagery.

3.3.4 Elevation Comparison

Figure 36 shows a representative sample of the elevation validation. Fifty (50) of the 3060 elevation check points show the relationship between the DSM from UAV imagery and LiDAR DEM compared to the elevation points of the NRTK GPS survey.

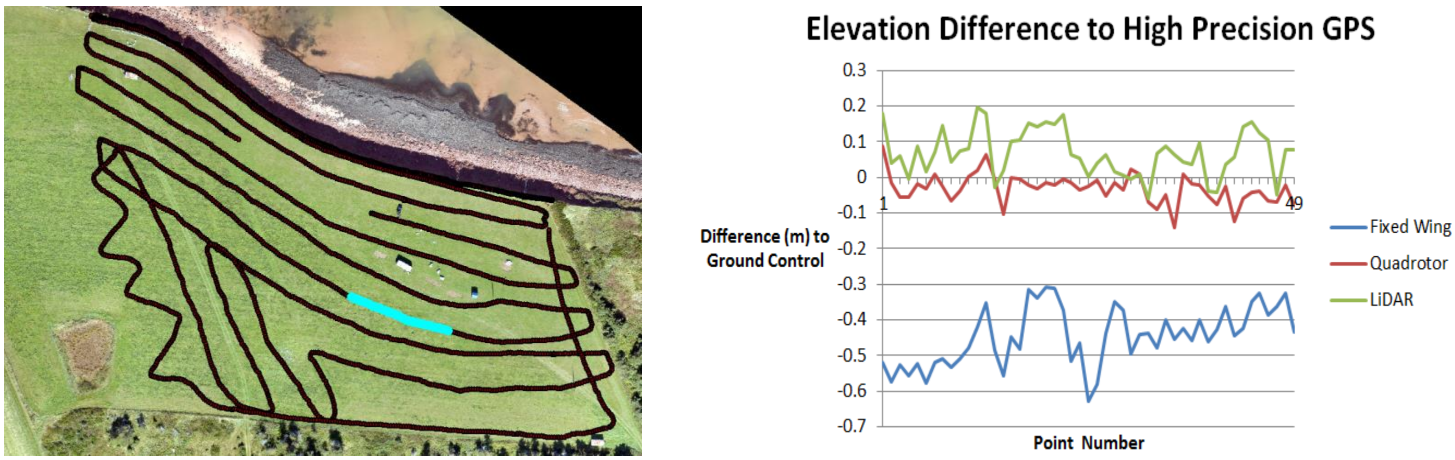

Figure 36: Subset of sampling points plotting the difference in DSM and LiDAR DEM to the GPS elevation points.

For this representative sample of 50 check points, the average differences to the ground control were calculated as fixed wing DSM : -0.404 m, quadcopter DSM : -0.043 m and LiDAR DEM: 0.068 m. Total averages across all 3,060 check points were calculated as; fixed wing DSM : -0.117 m, quadcopter DSM : -0.0224 m and LiDAR DEM: 0.038 m. Only elevation check points from the backshore were used in this analysis. Elevation check points at the base of the cliff were left out due to the introduction of potential errors. Namely, the different dates of data collection meant that the rocky shore could have changed due to tides and wave action. Also, the rocky shore made it difficult to maintain a constant elevation of GPS receiver leading to possible errors in the elevation points collected. For these reasons, confidence in the comparisons of datasets over this part of the study site was low and the 590 points were excluded from the elevation model validation. Also of note is the exclusion of the DSM that were not fully georeferenced. As demonstrated above, the spatial accuracies of these DSM are limited causing a shift in the imagery and DSM. These shifts would lead to sampling of different points on the ground, affecting overall confidence in the results.

The above calculations suggest the DSM of the UAV imagery are under-representing the real world elevations by 0.117 m and 0.022 m for the fixed wing and quadcopter respectively. Also apparent is the quadcopter is matching the ground truth data much better with an over 5 times improvement over the fixed wing vehicle. The data suggest the LiDAR DEM is over representing ground truth elevations by 0.038 m. Final conclusion of this data comparison suggest the fixed wing DSM does an adequate job compared to the ground truth elevations and the quadcopter DSM and LiDAR DEM do a very good job in representing real world elevations with the quadcopter DSM performing the best representation. Similar results have been seen in Flener (2013) and Hugenholtz (2012) suggesting that a DSM generated using imagery captured by a UAV flown at 90 m altitude can be used to detect change over time with a volumetric change analysis.

3.4 Chapter 3 Concluding Remarks

This chapter presented a comparative analysis between two sUAS: a fixed wing system and a VTOL quadcopter for the application to coastal environmental monitoring on Prince Edward Island, Canada. Low altitude flights (90 m) conducted for this study produced 0.035 m/pixel orthomosaics and DSM which provide a promising workflow for quantifying coastal change. Spatial accuracies were quantified by comparing GCP coordinates to GCP markers in orthomosaics and comparing the digitized cliff top edge to an NRTK GPS survey of the coastline. This study revealed an increased performance of the quadcopter (0.03 m) over the fixed wing aircraft (0.10 m) in georeferencing of GCP to their true location. Similar results were seen across the systems for delineating the cliff top edge - quadcopter (0.21 m), fixed wing (0.25 m). It has been determined that either system will produce an orthomosaic georeferenced well enough to monitor change in a cliff within the range of annual erosion (0.28 m) when a consistent workflow is implemented; however, the quadcopter is the preferred platform for several reasons. First, the ability for VTOL greatly simplifies mission execution and enables data collection at virtually any study site. A fixed wing system will require a sizable clearing for take-off and landing limiting the number of potential study sites or at least complicating mission execution. Second, is the influence of wind on the performance of each system. In practice, the quadcopter was easily able to handle windy conditions that the fixed wing could not where a calmer day was needed to execute the fixed wing's survey. This is of particular importance due to consistently windy conditions along the coast. The final advantage of the quadcopter over the fixed wing was in the efficiency in the number of flight lines needed to complete the survey. Far fewer flight lines were needed for the quadcopter compared to the fixed wing which resulted in fewer total images, increasing processing time and decreasing file size. Note that under favourable conditions a fixed wing equipped with adequate battery will be able to cover a larger area in a single flight. Also worth noting is the fixed wing used in this study offers a wide range of sensors that the quadcopter does not, opening the possibility of addition analysis or applications.

Elevations of the generated DSM were compared against the ground truth NRTK GPS survey of the study site and 2008 LiDAR DEM. The quadcopter's DSM had an average difference of -0.0224 m across 3,060 check points compared to the fixed wing's DSM at -0.117 m. Similarly, the quadcopter's DSM matched the LiDAR DEM more closely. Although both systems would provide accurate enough DSM for use in volumetric change analysis, sediment budgeting, or storm surge modelling, the improved accuracy and efficiency considerations lead to the determination that, within the context of this study, for monitoring coastal erosion at the human scale that the 3DRobotics Iris+ Mapper VTOL quadcopter is better suited. Results of this study are expected to translate to other coastal environments, dunes, wet lands, low plains, etc. but quality assessment of other representative coastlines will be the subject of future work as a comprehensive approach to coastal monitoring is developed.

Future work will involve the establishment of a provincial wide monitoring network using the methods described in this paper. Initially, cliff environments will be the focus with additional coastal environments coming later. A modified approach to dune and wetlands is expected and will require additional validation. Future work will also continue to validate emerging sUAS platforms and assess their practicality of adoption to an extensive coastal monitoring program. New technologies of interest include: onboard RTK GPS and base station for faster georeferencing; UAVs with longer endurance; and LiDAR mounted UAV to create bare earth elevation models where vegetation is present. Finally, future study will seek to adapt coastal monitoring programs to other coastal communities and small islands around the world, particularly those that have been identified as vulnerable to climate change.

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Chapter 4

4.1 Discussion

Two methods of monitoring coastal cliff and bluff environments on Prince Edward Island have been investigated in this thesis. Results and discussions of each method can be found in Chapters 2 and 3. Although terrestrial peg line measurements differ greatly from airborne imagery from UAV, both approaches serve to develop the understanding of small scale geomorphological changes and enhance the capacity to adapt to a changing climate in coastal areas. Table 1 below summarizes some key results and findings of this thesis and provides an assessment of each method's applicability to long term monitoring and adaptation to other coastal locals.

	Peg Line Monitoring	UAV Monitoring	
		Quadcopter	Fixed Wing
Cost - Materials and Equipment(Initial)	$1,000	$4,500 – UAV $21,000 – GPS	$41,000 – UAV $21,000 – GPS
Maintenance and ongoing costs	- Travel and personnel	$1,200 – GPS Travel and personnel	$1,200 – GPS $5,000 – UAV Travel and personnel
Time Involved (At Site)	30 minutes	30 – 60 minutes	30 – 60 minutes
Skills Required	Understanding of measurement system	Knowledge of airspace, Specialized Software, Intermediate flight control, GIS and processing	Knowledge of airspace, Specialized Software, Advanced flight control, GIS and processing
Regulation/Safety Concerns	Permissions	Permissions	Permissions

	Raised stakes – tripping hazard	Transport Canada compliance Public Safety	Transport Canada compliance Public Safety
Data Output	Point measurements	High resolution DSM and orthomosaic	High resolution DSM and orthomosaic
Accuracy	+/-20 cm	21 cm – XY 2.24 cm – Z	25 cm – XY 11.7 cm – Z
Limitations	Cliffs and Bluffs (Consistent indicator feature required) Personnel	Not limited by take-off and landing locations Personnel	Limited by good take-off and landing locations Personnel

Table 3: Summary of key attributes of terrestrial and airborne UAV monitoring methods.

Summarizing the key factors presented in Table 4, it can be seen that the initial cost of a peg line monitoring method is quite low only requiring the purchase of basic materials ($1,000): metal rebar stakes, measuring tape, gloves, recreational GPS, and mallets. Ongoing cost will also be limited requiring only funds for travel and personnel to take annual measurements and data management. The cost of the two sUAS used in this study varied by an order of magnitude. The cost of the Iris+ Mapper ($4,500) was much less than the PrecisionHawk Lancaster Rev 3 ($41,000) with both systems requiring a survey grade GPS ($21,000) and subscription to Network based Differential Correction service ($1,200/year). The fixed wing system offers ongoing replacement insurance ($5,000/year) that the quadcopter system does not which results in a higher ongoing operational cost. Software, field computer, and processing computer are required for either system but can vary widely depending on researcher’s preferences and budget. Travel and personnel costs are generally the same for all approaches with additional personnel costs required to process UAV data. Liability insurance is not purchased directly but is included under the University's policy.

The time required at site is less for the peg line measurements (30 minutes). Once the pins are found, the measurement is taken and time on site is complete. Time required at site for the sUAS is more or less equal to one another but consistently longer than peg line measurements due to the added complexity to complete a mission. Site assessment, GCP measurement, and mission execution are the time consuming components. Skills required for each method and system varies. Peg line measurements requires understanding of the measurement mechanics, transect design and location selection, and recognition of geomorphic features. Within the scope of this work, these skills are believed to be easily transferred by field notes and experienced personnel. Operating a fixed wing system is considerably more difficult than operating a VTOL quadcopter, particularly when manual control is needed, although both will require a certain level of training and experience. Landing a fixed wing aircraft is more difficult due to space requirements and influence of wind on landing accuracy. In the event of an emergency where manual control is required, additional experience is needed to safely control a fixed wing UAV.

Operating a UAV for research will require knowledge of airspace principles, regulation and compliance, and public safety. Transport Canada regulates the use of UAVs and requires a Special Flight Operations Certificate (SFOC) to conduct UAV surveys for research. Experience and commitment to safety are detailed in the applicant's submission along with detailed specifications of the aircraft and intended use. Transport Canada requires permission of the land owners from which the flights are conducted (take-off and landing). Concerns of safety and regulation are limited for peg line measurements. Generally, written permission of the land owner is good practice with attention to peg installations to limit the possibility of unintended interaction.

Methods described greatly differ in their data usefulness where peg line measurements only provide point data difference in the coastline; sUAS produce high resolution orthomosaics and DSM that can be used in a variety of analysis and model inputs. This study has shown slightly better results in data accuracy for the quadcopter versus the fixed wing. Peg line measurements are subject to several areas of human error and are considered less accurate. Limitations of the peg line measurement method arise from the inability of this method to consistently and easily identify shoreline indicator features in environments outside of cliffs and bluffs. For example, peg line measurements in dune and wetland environments present challenges in site establishment and measurements and are outside the scope of this thesis. It is expected that a quadcopter can operate in virtually any environment, however, a fixed wing aircraft will be limited by site characteristics due to landing requirements. Personnel can also be considered a limitation for each of these methods where experienced and knowledgeable personnel are needed on an ongoing basis to complete the work annually and train new personnel with the required skills.

Based on the findings of this study, a long term monitoring program is considered to be very feasible using the peg line measurement method and quadcopter method. The feasibility of such a monitoring program is considered less feasible for a fixed wing system largely due to the requirements for safe take-offs and landings. Additionally, the influence of wind on consistent operation and data quality results in a less feasible method. Consistent winds can be expected along any coast so a system that can handle moderate winds easily is necessary for long term adoption. Ultimately, overall cost and data requirements will dictate the method employed; therefore, based on the findings of this study it is the recommendation of the authors that a sufficiently sophisticated quadcopter is the best approach for long term monitoring of coastal areas at high resolution spatial scales and fine temporal scale of many sites.

4.2 Conclusion

The goal of this thesis was to develop and assess methodologies for detecting coastal erosion of cliff and bluff environments on Prince Edward Island, Canada. There was an emphasis on cost and scalability which lead to the ultimate approach using a terrestrial direct measurement method and use of an emerging technology known as small Unmanned Aerial Systems (sUAS). These methods were chosen in favour of traditional methods using manned aircraft or RTK GPS surveys with the expectation that the methods in question provide a temporal and spatial scale improvement along with an ability to scale the method to other small islands or coastal areas.

Throughout this study, a historical terrestrial peg line measurement monitoring program was resurrected, improved, and built upon. This method's major advantages are in the low cost to establish and maintain the monitoring network and ability to easily take annual measurements. This method can provide point measurements of coastal erosion across many sites and is best suited as a starting point for coastal communities with extensive cliff and bluff systems looking to quantify coastal change. Measurements taken during the 2014 and 2015 fields seasons at 74 sites resulted in an average loss of 0.46 m with an uncertainty of +/- 20 cm. Unfortunately this approach is limited in the amount of analysis that can be completed on this data but provides a low cost, agile way to quantify coastal erosion trends of cliff and bluff environments. Measurement data can be supplemented by detailed notes of the study site indicating areas of slumping, elevation and slope, geomorphic descriptions, and pictures for visualizing any change. Images taken at measurement sites can provide a snapshot of the state of the costal environment. Additionally, monitoring coastal change of other type of coastlines using this method would be difficult because of the lack of definitive shoreline indicator features. Future work could involve the methodological development for other representative coastlines. Overall, this method is less preferred to more advanced data collection methods including using sUAS as described in this thesis, particularly for communities that have the funding and geospatial expertise to implement a more sophisticated approach.

The use of sUAS was believed to satisfy all parametres in creating a successful long term monitoring program. Results of photogrammetrically derived orthomosaics and DSM from UAV imagery were seen to have comparable accuracies to manned aircraft and NRTK GPS surveys. Because of the low flying altitude of UAV, higher spatial resolution is possible using cheaper sensors than those used on manned aircraft. Although UAV flights have smaller extents compared to manned flights, the technology enables many sites to be easily surveyed over a given field season. Overall, through experience using the technology and results of the accuracy assessment in this thesis and in the literature, UAV provide a low cost, data rich, and agile tool for detecting change along the coast. The comparative analysis of fixed wing and quadcopter platforms completed in this work suggest a quadcopter based platform is better suited for coastal research because of the versatility of VTOL and ability to handle high sustained winds. Although this study looks specifically at a coastal cliff environment, it is expected that the quality of data output will enable change detection for all coastal environments including dunes and wetlands. This will require a modified definition of the coastal indicator feature and will be the subject of future work. This method’s largest impact rests in the scientific community and local to regional scale government. This thesis merely scratches the surface of scientific analysis of coastal environments but has demonstrated its feasibility. Local to regional governments can benefit greatly from the developed methodology for monitoring of vital infrastructure and influence decision making.

Future work will surround the refinement of monitoring methods and application to all coastal environments. Emerging technologies hold the potential to increase the spatial extent of monitoring locations, improve accuracy, and limit field time. Therefore, there is the possibility to modify methods based on the technology available. This thesis has laid the ground work for the adoption of a long term monitoring program on Prince Edward Island, Canada using emerging UAV technology and low cost terrestrial measurements. These methods provide the realistic potential for this work to be adapted to other small islands and coastal areas around the world as a component to build resilience and enhance coastal adaptation capabilities. Future efforts will be made to visualize and communicate ongoing results based on the study using a web based platform.

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Appendix A

Site Number & Location	Date Established	Latitude	Longitude	X	Y	Date Measured	Observer	Distance Measured	Distance in meters	Elevation (m)
Anglo Recreation A Park P-9	8/8/1986									
		Ref: N 46 58.710	W 063 59.548	324493.9455	770297.6162	8/8/1986	Philip Ward	136'-5"	41.58	Ref: 10.423702
		End: N 46 58.703	W 063 59.503	324550.6973	770284.7781	30/10/1992	Philip Ward	122'-0"	37.19	End: 9.888252
						11/7/2014	S.B.	192'-2"		
						Site abandoned				
B		Ref: N 46 58.702	W 063 59.554	324485.7022	770283.6017	8/8/1986	Philip Ward	139'-4"	42.47	Ref: 9.931244
		End: N 46 58.695	W 063 59.504	324548.9868	770269.9025	30/10/1992	Philip Ward	120'-2"	36.63	End: 9.281178
						11/7/2014	S.B.	202'-10"		
*Changehouse must have been moved back						Site abandoned				
park has been shut down for long time										
C	22/09/2015	N 46.97828	W 63.99189			22/09/2015	Andy MacDonald		10	
Annandale K3 A	23/09/2014	N 46.25975	W -62.4246							
						23/09/2014	Don Jardine, Derek Ellis		27.2	
						26/08/2015	Andy MacDonald		27.2	
B	23/09/2014	N 46.25978	W -62.42487			23/09/2014	Don Jardine, Derek Ellis		12.35	
						26/08/2015	Andy MacDonald		12.15	
C	23/09/2014	N 46.25913	W -62.42197			23/09/2014	Don Jardine, Derek Ellis		6.5	
						26/08/2015	Andy MacDonald		6.2	
D	23/09/2014	N 46.259236	W -62.422204			23/09/2014	Don Jardine, Derek Ellis		19.8	
						26/08/2015	Andy MacDonald		19.8	
Argyle Shore East pt. Q-15	16/07/1985	N 46 10.223	W 063 22.950	370461.8001	680062.5242					12.970928
						16/07/1985	Philip Ward	50'-9"	15.47	
						22/07/1986	Philip Ward	50'-8"	15.44	
						3/5/1989	Philip Ward	40'-8"	12.395	
						12/6/2014	S.B., D.E., & D.J.	5'-5"	1.65	
						2015-15-07	Andy MacDonald		1.15	
						2015-15-07	Andy MacDonald		*new rebar installed* 10.21	

Argyle Shore West pt. Q-15	16/07/1985	N 46 10.245	W 063 23.128	370232.9547	680105.102					16.085678
						16/07/1985	Philip Ward	38'-6"	11.74	
						22/07/1986	Philip Ward	38'-6"	11.74	
						3/5/1989	Philip Ward	35'-0"	10.67	
						12/6/2014	S.B., D.E., & D.J.	6'-3"	1.91	
						2015-15-07	Andy MacDonald		0.48	
						2015-15-07	Andy MacDonald		*new rebar installed* 10.33	
Belle River (Richard Davies) Cliff #1	12/08/2014	N 45.989133	W -62.872666							
						12/08/2014	Don Jardine		12.19	
						01/12/2014	Don Jardine, Derek Ellis		11.7	
						09/09/2015	Andy MacDonald		11.55	
Cliff #2	12/08/2014	N 45.98883	W - 62.87255			12/08/2014	Don Jardine		9.68	
						01/12/2014	Don Jardine, Derek Ellis		9.5	
						09/09/2015	Andy MacDonald		9.27	
Dune #1	12/08/2014	N 45.989516	W - 62.87285			12/08/2014	Don Jardine		13.72	
						01/12/2014	Don Jardine, Derek Ellis		13.26	
						09/09/2015	Andy MacDonald		13.15	
Blockhouse LH Q-9	9/7/1984	N 46 11.435	W 063 07.756	390020.6325	682245.4977					13.521779
						9/7/1984	Philip Ward	98'-8"	30.07	
						26/06/1985	P.K.W.	87'-10"	26.77	
						3/5/1989	P.K.W. & K.C.	84'-8"	25.81	
						12/11/1996	P.W. & Jeff Thompson	75'-3"	22.94	
						14/10/1999	Kathy Bunnie	64'-4"	19.61	
						3/5/2011	D.J.	64'-0"	19.51	
						12/6/2014	S.B., D.E., & D.J.	65'-0"	19.81	
						2015-16-07	Andy MacDonald		18.75	
Borden (John's House)	12/6/2014	N 46 15.032	W 063 41.700	346407.081	689136.5748					8.413162
						12/6/2014	S.B., D.E., & D.J.	43'-0"	13.11	
						3/5/2015	Andy MacDonald		12.8	

Borden LH P-2	16/07/1985	N 46 15.012	W 063 41.654	346465.895	689098.7053				
						9/7/1984	Philip Ward	44'-3"	13.49
						26/06/1985	Philip Ward	43'-10"	13.36
						18/06/1986	Philip Ward	43'-10"	13.36
						3/5/1989	P.W. & K.C.	43'-10"	13.36
						12/11/1996	P.W. & J.T.	38'-0"	11.58
						14/10/1999	C.M. & D.R.	36'-4"	11.07
						15/12/2010	D.J.	30'-9"	9.37
						12/6/2014	S.B., D.E., & D.J.	30'-2"	9.19
						3/8/2015	Andy MacDonald		9.15
Cable Head K-12	30/10/1984	Ref: N 46 28.014	W 062 37.395	428936.1307	713019.7828				
		End: N 46 28.032	W 062 37.398	428932.2062	713053.3336	30/10/1984	Philip Ward	142'-2"	43.33
						12/6/1985	Philip Ward	140'-0"	42.67
						29/05/1986	Philip Ward	139'-0"	42.37
						1/6/1987	Philip Ward	138'-0"	42.06
						28/04/1989	Philip Ward	137'-6"	41.91
						5/11/1992	Philip Ward	127'-0"	38.71
						29/11/1995	P.W. & A.M.	125'-0"	38.1
						7/11/1996	P.W. & J.T.	121'-0"	36.88
						10/8/1998	J.T. & J.D.	116'-9"	35.59
						3/12/2010	A.M.	112'-0"	34.14
						9/6/2011	D.J.	112'-0"	34.14
						10/7/2014	S.B.	114'-4"	34.85
						17/08/2015	Andy MacDonald		33.4
Campbell's Cove Park K-6	11/6/1984								
						11/6/1984	Philip Ward	61'-4"	18.69
						12/6/1985	Philip Ward	60'-8"	18.49
						29/05/1986	Philip Ward	60'-1"	18.31
						1/6/1987	Philip Ward	60'-0"	18.29
						28/04/1989	Philip Ward	57'-6"	17.53
						29/11/1995	Philip Ward	Pins gone	Pins gone
						Site lost			
B		Ref: N 46 28.766	W 062 08.352	466098.2702	714705.6064	17/11/2010	D.J.	16'-0"	4.88
**Post must have been moved		End: N46 28.769	W 062 08.343	466109.8782	714711.5143	10/7/2014	S.B.	22'-7"	6.88
						13/08/2015	Andy MacDonald		6.6
C	13/08/2015	N46.47940	W -62.13929			13/08/2015	Andy MacDonald		10

Canoe Cove Park Q-14 A	16/07/1985	N 46 08.810	W 063 18.278	376464.6308	677419.8188					14.480776
						16/07/1985	Philip Ward	139'-0"	42.37	
						3/5/1989	P.K.W. & K.C.	135'-8"	41.35	
						12/11/1996	P.W. & J.T.	133'-0"	40.54	
						13/10/1999	Kathy Bunnie	132'-3"	40.31	
						3/5/2011	D.J.	125'-6"	38.25	
						12/6/2014	S.B., D.E., & D.J.	124'-1"	37.82	
						2015-16-07	Andy MacDonald		37.61	
B	16/07/2015	N 46.14637	W -63.30325			16/07/2015	Andy MacDonald		9.99	
C	16/07/2015	N 46.14637	W -63.30418			16/07/2015	Andy MacDonald		9.99	
D	16/07/2015	N 46.14705	W -63.30496			16/07/2015	Andy MacDonald		10	
Cape Bear (Beach Point) K-1	12/6/1984	N 46 00178	W 062 27.608	441818.0219	661525.4545					24.94746
						12/6/1984	Philip Ward	44'-4"	13.51	
						11/6/1985	Philip Ward	44'-4"	13.51	
						13/05/1986	Philip Ward	44'-4"	13.51	
						15/06/1987	Philip Ward	44'-4"	13.51	
						27/04/1989	Philip Ward	38'-9"	11.81	
						7/11/1996	P.W. & T.C.	30'-8"	9.35	
						30/12/1998	P.W. & J.T.	30'-0"	9.14	
						19/10/1999	J.T. & G.W.	29'-2"	8.89	
						14/05/2002	Kathy Candy	27'-4"	8.33	
						23/12/2010	P.W. & D.C.	19'-3"	5.87	
						8/9/2011	D.J.	19'-0"	5.79	
						8/7/2014	S.B.	14'-5"	4.39	
						Lighthouse was moved				
B	20/08/2015	N 46.00331	.45777			20/08/2015	Andy MacDonald		10	
C	20/08/2015	N 46.00293	2.46029			20/08/2015	Andy MacDonald		10	

Cape Egmont LH P-6 A	26/06/1985	Ref: N 46 24.109	W 064 08.043	312795.0319	706345.6675					Ref: 9.566302
*LH moved in 1998		End: N 46 24.093	W 064 08.036	312803.8356	706316.1909	26/06/1985	Philip Ward	42'-5"	12.93	End: 9.89572
						22/07/1986	Philip Ward	42'-5"	12.93	
						3/5/1989	Philip Ward	37'-6"	11.43	
						12/11/1996	P.W. & J.T.	35'-4"	10.77	
						6/1/1999	Jeff Thompson	109'-4"	33.33	
						11/7/2014	S.B.	100'-1"	30.51	
						06/08/2015	Andy MacDonald		30.15	
B	10/09/2015	N 46.40164	W -64.13462			10/09/2015	Andy MacDonald		10	
C	10/09/2015	N 46.40172	W -64.13457			10/09/2015	Andy MacDonald		10	
D	10/09/2015	N 46.41097	W -64.13425			10/09/2015	Andy MacDonald		10	
E	10/09/2015	N 46.40173	W -64.13463			10/09/2015	Andy MacDonald		9.18	

Cherry Cliff (Earnscliffe) Q-3	8/6/1984									
						8/6/1984	Philip Ward	28'-4"	8.64	
						11/6/1985	Philip Ward	28'-4"	8.64	
						13/05/1986	Philip Ward	28'-4"	8.64	
						25/05/1987	Philip Ward	28'-4"	8.64	
						8/7/2014	S.B.	No Pins	No Pins	
						Site lost				
B	8/7/2011	N 46 08.423	W 062 57.828	402797.55	676657.5343	8/7/2014	S.B.	48'-8"	14.83	15.455112
						10/08/2015	Andy MacDonald		14.4	
Clear Springs K-8	30/10/1984									
						30/10/1984	Philip Ward	64'-8"	19.71	
						24/05/1986	Philip Ward	63'-8"	19.4	
						1/6/1987	Philip Ward	61'-5"	18.72	
						28/04/1989	Philip Ward	60'-2"	19.34	
						29/11/1995	A.D.M. & P.W.	No Pins	No pins	
						Site lost				
B						15/05/2003	P.W. & D.C.	41'-8"	12.7	
		Ref: N 46 28.104	W 062 21.309	449526.1217	713320.1323	9/6/2011	D.J.	35'-0"	10.668	Ref: 17.896431
only front pin and starting to be overgrown		End: N46 28.109	W 062 21.309	449526.3531	713329.3605	10/7/2014	S.B.	32'-0"	9.75	End: 14.049846
						17/08/2015	Andy MacDonald		9.3	

Conway Sandhills P1 A	26/08/2014	N 46.73308	W -63.982878							
						26/08/2014	pn Jardine, Andrew Clark		12.19	
B	26/08/2014	N 46.732199	W -63.981423			26/08/2014	pn Jardine, Andrew Clark		11.89	
C	26/08/2014	N 46.731782	W -63.982248			26/08/2014	pn Jardine, Andrew Clark		12.19	
D	26/08/2014	N 46.732199	W -63.981423			26/08/2014	pn Jardine, Andrew Clark		12.19	
Cousins Shore Q-11	6/11/1984	N 46 32.383	W 063 33.271	357466.6997	721195.6938					17.837326
						6/11/1984	Philip Ward	150'-4"	45.82	
						13/06/1985	Philip Ward	149'-6"	45.57	
						18/06/1986	Philip Ward	147'-1"	44.83	
						2/5/1989	P.W. & M.M.	146'-1"	44.53	
						12/11/1996	P.W. & J.T.	165'-0"?	50.29	
						23/07/1999	J.T. & N.C.	153'-3"?	46.71	
						13/06/2014	S.B. & D.C.	136'-5"	41.58	
						27/07/2015	Andy MacDonald		42.55	
Darnley LH P-3	6/11/1984	N 46 33.846	W 063 39.085	350057.5799	723962.6267					19.310072
						6/11/1984	Philip Ward	94'-0"	28.65	
						13/06/1985	Philip Ward	94'-0"	28.65	
						18/06/1986	Philip Ward	93'-2"	28.397	
						2/5/1989	P.W. & M.M.	93'-2"	28.397	
						23/07/1999	J.T. & N.C.	88'-0"	26.82	
						15/12/2010	D.J.	63'-0"	19.2	
						13/06/2014	S.B. & D.C.	81'-4"	24.79	
						29/07/2015	Andy MacDonald		24.64	

East Pt. A K-15	12/6/1985									
						12/6/1985	Philip Ward	62'-8"	19.1	
						29/05/1986	Philip Ward	61'-9"	18.82	
						1/6/1987	Philip Ward	60'-4"	18.39	
						28/04/1989	Philip Ward	59'-0"	17.98	
						29/11/1995	P.W. & A.M.	48'-0"	14.63	
						7/11/1996	P.W. & J.T.	48'-0"	14.63	
						10/8/1998	J.T. & J.D.	48'-0"	14.63	
						14/05/2003	P.W. & D.C.	36'-8"	11.18	
						Site lost				
B		N 46 27.176	W 061 58.282	479024.8636	711914.7589	29/09/2011	D.J.	16'-0"	4.89	16.9007
						7/7/2014	S.B.	13'-2"	4.01	
						13/08/2015	Andy MacDonald		3	
C		W: N 46 27.247	W 061 58.601	478613.9955	712040.904	Summer 2010	Fred Cheverie	W, E, M:32'-10"	W, E, M: 10	W: 14.566708
		M: N 46 27.239	W 061 58.565	478660.4357	712026.6127	Fall 2010	Fred Cheverie	W:32'-8", M:32'-8", E:32'-8"	W:9.95, M:9.98, E:9.96	M: 15.061377
		E: N 46 27.234	W 061 58.528	478708.0848	712019.7859	Spring 2011	Fred Cheverie	W:15'-8", M:15"-9", E:17'-8"	W:4.78, M:4.81, E:5.4	E: 16.262158
						Fall 2012	Fred Cheverie	W:14'-5", M:13'-3", E:12'-9"	W:4.4, M:3.97, E:3.68	
						Spring 2013	Fred Cheverie	W:14'-4", M:12'-8", E:12'-1"	W:4.38, M:3.85, E:3.69	
						Spring 2014	F.C., S.B., D.J., D.E.	V:13'-9", M:12'-3", E:11'-11.	W:4.2, M:3.73, E:3.65	
						7/7/2014	S.B.	W:13'-9", M:11'-8", E:12'-1"	W:4.2 , M:3:56 , E:3.69	
						13/08/2015	Andy MacDonald		W:4.2 , M:3.56 , E:3.6	
Fernwood A	14/10/2015	N 46.32024	-63.79145							
						14/10/2015	Andy MacDonald		10	
B	14/10/2015	N 46.32029	W -63.79171			14/10/2015	Andy MacDonald		10	
C	14/10/2015	N 46.32032	W -63.79207			14/10/2015	Andy MacDonald		10	
Goose River K-10	30/10/1984									
						30/10/1984	Philip Ward	75'-8"	23.06	
						12/6/1985	Philip Ward	75'-5"	22.99	
						29/05/1986	Philip Ward	75'-1"	22.59	
						1/6/1987	Philip Ward	75'-0"	22.86	
						28/04/1989	Philip Ward	74'-1"	22.58	
						29/11/1995	P.W. & A.M.	67'-0"	20.42	
						7/11/1996	P.W. & J.T.	66'-8"	20.32	
						10/8/1998	J.T. & J.D.	65'-0"	19.812	
K-10 B						3/12/2010	D.J.	18'-0"	5.49	
**Pins lost due to clearing of an area						10/7/2014	S.B.	No Pins	No pins	
K-10C		Ref: N 46 28.154	W 062 31.328	436701.9474	713322.3774	3/12/2010	D.J.	315'-0"	96.01	Ref: 13.941598
		End: N 46 28.202	W 062 31.353	436669.2274	713410.9942	9/6/2011	D.J. & A.M.	314'-0"	95.71	End: 13.403387
						10/7/2014	S.B.	311'-11"	95.072	
						17/08/2015	Andy MacDonald		95	
D	08/17/2015	N 46.47002	W -62.52249			08/17/2015	Andy MacDonald		5	

Governor's Island Q1 A	18/09/2014	N 46.134717	W -63.056996							
						18/09/2014	Don Jardine, Derek Ellis		12.19	
						02/09/2015	Andy MacDonald		10.08	
B	18/09/2014	N 46.133447	W -63.058815			18/09/2014	Don Jardine, Derek Ellis		12.19	
						02/09/2015	Andy MacDonald		11.45	
C	18/09/2014	N 46.133297	W -63.060461			18/09/2014	Don Jardine, Derek Ellis		12.19	
						02/09/2015	Andy MacDonald		11.5	
Hampton Q4 A	07/10/2014	N 46.188872	W -63.44016							
						07/10/2014	Don Jardine, Derek Ellis		10	
						13/07/2015	Andy MacDonald		10	
B	07/10/2014	N 46.189001	W -63.441535			07/10/2014	Don Jardine, Derek Ellis		10	
						13/07/2015	Andy MacDonald		9.75	
C	07/10/2014	N 46.189129	W -63.442281			07/10/2014	Don Jardine, Derek Ellis		8	
						13/07/2015	Andy MacDonald		7.8	
D	07/10/2014	N 46.189131	W -63.442894			07/10/2014	Don Jardine, Derek Ellis		6	
						13/07/2015	Andy MacDonald		5.9	
E	07/10/2014	N 46.189137	W -63.443245			07/10/2014	Don Jardine, Derek Ellis		6	
						13/07/2015	Andy MacDonald		5.95	
F	07/10/2014	N 46.189191	W -63.444003			07/10/2014	Don Jardine, Derek Ellis		10	
						13/07/2015	Andy MacDonald		9.84	
G	07/10/2014	N 46.189024	W -63.445511			07/10/2014	Don Jardine, Derek Ellis		10	
						13/07/2015	Andy MacDonald		9.78	
H	07/10/2014	N 46.188802	W -63.446425			07/10/2014	Don Jardine, Derek Ellis		10	
						13/07/2015	Andy MacDonald		9.75	
I	07/10/2014	N 46.187909	W -63.447566			07/10/2014	Don Jardine, Derek Ellis		10	
						13/07/2015	Andy MacDonald		9.8	
J	07/10/2014	N 46.187353	W -63.448038			07/10/2014	Don Jardine, Derek Ellis		10	
						13/07/2015	Andy MacDonald		9.2	

Hebrides Q2 A	30/09/2014	N 46.494997	W -63.479691							
						30/09/2014	on Jardine, Andrew Clark		10	
						29/07/2015	Andy MacDonald		9.85	
B	29/07/2014	N 46.49332	W -63.47901			29/07/2015	Andy MacDonald		10	
C	29/07/2014	N 46.49229	W -63.47935			29/07/2015	Andy MacDonald		10	
Howe Pt. K-4	11/6/1984	N 46 18.283	W 062 20.343	450915.7624	695136.97					38.36998
						11/6/1984	Philip Ward	22'-8"	6.91	
						12/6/1985	Philip Ward	22'-8"	6.91	
						6/5/1986	Philip Ward	22'-7"	6.88	
						27/04/89	P.W. & T.C.	21'-2"	6.45	
						Site lost	S.B.			
B	26/08/2015	N 46.30449	W -62.34350			26/08/2015	Andy MacDonald		10	
C	26/08/2015	N 46.30434	W -62.34470			26/08/2015	Andy MacDonald		10	
KN-1 (Kite Pt.)	11/6/2012	N 46 32.041	W 063 43.967	343788.5927	720672.9263					6.966701
						6/11/2012	D.C.	54'-9"	16.69	
						22/11/2013	D.C.	53'-1"	16.2	
						13/06/2014	S.B. & D.C.	50'-5"	15.37	
						2015-29-07	Andy MacDonald		15.16	
KN-3	6/11/2012	N 46 32.698	W 063 43.228	344743.902	721881.2063					18.85906
						6/11/2012	D.C.	68'-3"	20.82	
						22/11/2013	D.C.	71'-9"	21.88	
						13/06/2014	S.B. & D.C.	69'-10"	21.29	
						Site abandoned				
B		N 46 54.495	W 063 72.046			13/06/2014	S.B. & D.C.	53'-2"	16.22	
						29/07/2015	Andy MacDonald		16.75	
C		N 46.54485	W -63.72063			29/07/2015	Andy MacDonald		10	

KN-4 (Cabot Park)	2012	N 46 33.595	W 063 42.083	346222.3873	723530.6977					19.240223
						6/11/2012	D.C.	11'-8"	3.58	
						22/11/2013	D.C.	11'-9"	3.6	
						13/06/2014	S.B. & D.C.	8'-2"	2.49	
						29/07/2015	Andy MacDonald		2.55	
KN-5 (coulson cottage)	6/11/2012	N 46 32.977	W 063 41.504	346952.0209	722378.1324					17.180904
						6/11/2012	D.C.	33'-3"	10.15	
						22/11/2013	D.C.	32'-9"	10	
						13/06/2014	S.B. & D.C.	32'-9"	10	
						29/07/2015	Andy MacDonald		10	
B	16/06/2014	N 46 54961	W 063 69.174			13/06/2014	S.B. & D.C.	25'-7.5"	7.81	
						29/07/2015	Andy MacDonald		6.98	
KN-6 (rte 20, Rubens Lane)	6/11/2012	N 46 32.252	W 063 39.993	348871.7476	721018.0093					21.037249
						6/11/2012	D.C.	134'-2"	40.9	
						22/11/2013	D.C.	129'-11"	39.62	
						13/06/2014	S.B. & D.C.	129'-9"	39.55	
						Site abandoned				
	B					13/06/2014	S.B. & D.C.	50'-0"	15.24	
						29/07/2015	Andy MacDonald		15.24	
	C	N 46.53754	W -63.66654			29/07/2015	Andy MacDonald		10	
KN-7	6/11/2012	N 46 34.018	W 063 39.922	348989.8522	724289.2884					21.606247
						6/11/2012	D.C.	62'-7"	19.1	
						22/11/2013	D.C.	62'-3"	18.98	
						13/06/2014	S.B. & D.C.	61'-8"	18.796	
						29/07/2015	Andy MacDonald		18.72	

KN-8 (thunder cove Rd.) A	6/11/2012	N 46 33.736	W 063 38.443	350876.1758	723752.2373					16.338955
						6/11/2012	D.C.	29'-2"	8.9	
						22/11/2013	D.C.	28'-8"	8.75	
						13/06/2014	S.B. & D.C.	28'-10"	8.79	
						29/07/2015	Andy MacDonald		8.67	
B		N 46.56233	54089			29/07/2015	Andy MacDonald		10	
KN-10	6/11/2012	N 46 32.868	W 063 34.948	355330.0115	722109.1284					14.260553
						6/11/2012	D.C.	9'-11"	3.04	
						22/11/2013	D.C.	7'-2"	2.2	
						13/06/2014	S.B. & D.C.	5'-11"	1.8	
						03/08/2015	Andy MacDonald		1.63	
KN-10a	2012	N 46 32.854	W 063 34.891	355402.1384	722082.693					18.116896
						6/11/2012	D.C.	50'-10"	15.5	
						22/11/2013	D.C.	50'-5'	15.37	
						13/06/2014	S.B. & D.C.	48'-10"	14.88	
						Site lost				
C		N 46.54766	W -63.58146			03/08/2015	Andy MacDonald		10	
KN-11	6/11/2012	N 46 32.716	W 063 34.352	356090.4141	721822.2956					24.089022
						6/11/2012	D.C.	76'-1"	23.21	
						22/11/2013	D.C.	76'-4"	23.27	
						13/06/2014	S.B. & D.C.	75'-4.5"	22.97	
						03/08/2015	Andy MacDonald		22.72	

Lakeville K1 A	28/10/2014	N 46.47351	W -62.10712							24.089022
						28/10/2014	Don Jardine, Derek Ellis		10	
						13/08/2015	Andy MacDonald		9.95	
B	28/10/2014	N 46.47343	W -62.10632			28/10/2014	Don Jardine, Derek Ellis		10	
						13/08/2015	Andy MacDonald		10	
C	28/10/2014	N 46.47331	W -62.10545			28/10/2014	Don Jardine, Derek Ellis		10	
						13/08/2015	Andy MacDonald		9.9	
Linkletter Provincial Park P-4	26/06/1984									
						26/06/1985	Philip Ward	15'-6"	4.72	
**concrete pit gone 1996						22/07/1986	Philip Ward	15'-0"	4.57	
						3/5/1989	Philip Ward	11'-6"	3.51	
						12/11/1996	Philip Ward	No more Pit	No more pit	
						Site abandoned				
B		Ref: N 46 23.913	W 063 51.468	334033.2818	705713.3438	11/7/2014	S.B.	96'-2"	29.31	Ref: 13.05785
**goes from grass to beach but there is		End: N 46 23.900	W 063 51.477	334022.2439	705688.5633	03/08/2015	Andy MacDonald		29.15	End: 11.301285
a depression that must be felt for										
don't just measure to the tall grass line										
Naufrage K-9	30/10/1984	Ref: N 46 28.204	W 062 25.304	444411.7771	713466.0474					18.07213
		End: N 46 28.218	W 062 25.301			30/10/1984	Philip Ward	124'-4"	37.897	
						12/6/1985	Philip Ward	124'-0"	37.795	
						29/05/1986	Philip Ward	123'-8"	37.69	
						1/6/1987	Philip Ward	123'-0"	37.49	
						28/04/1989	Philip Ward	117'-3"	35.74	
						29/11/1995	P.W. & A.M.	114'-0"	34.75	
						7/11/1996	P.W. & J.T.	114'-0"	34.75	
						10/8/1998	J.T. & J.D.	106'-3"	32.39	
						19/08/1999	J.T., C.Q., & D.M.	99'-2"	30.23	
						1/12/2010	D.J.	117'-0"	35.66	
						3/12/2010	A.M.	103'-0"	31.39	
						10/7/2014	S.B.	95'-0"	28.956	
						17/08/2015	Andy MacDonald		26.4	

North cape. A P-8	8/8/1986	Ref: N 47 03.373	W 063 59.696	324416.3817	778939.435					Ref: 8.888509
		End: N 47 03.377	W 063 39.688	324426.59	778947.532	8/8/1986	Philip Ward	123'-2"	37.54	End: 9.005971
						30/10/1992	Philip Ward	117'-0"	35.66	
						14/10/1999	D.R. & C.M.	104'-9"	31.93	
						11/7/2014	S.B.	62'-5"	19.03	
						22/09/2015	Andy MacDonald		18.7	
B	30/12/2010					30/12/2010	D.J.	53'-6"	16.31	
						Site abandoned				
C	22/09/2015	N 47.05452	/ -63.99382			22/09/2015	Andy MacDonald		15	
D	22/09/2015	N 47.05842	W -63.99744			22/09/2015	Andy MacDonald		27	
E	22/09/2015	N 47.05026	-64.00396			22/09/2015	Andy MacDonald		36.63	
North Lake K2 A	28/10/2014	N 46.470302	W -62.079806							
						28/10/2014	on Jardine, Andrew Clark		10	
						13/08/2015	Andy MacDonald		10	
B	28/10/2014	N 46.470529	W -62.081002			28/10/2014	on Jardine, Andrew Clark		10	
						13/08/2015	Andy MacDonald		9.9	
C	28/10/2014	N 46.471139	W -62.082663			28/10/2014	on Jardine, Andrew Clark		10	
						13/08/2015	Andy MacDonald		9.15	
Northumberland Park Q-1	8/6/1984									
Only front rebar is left, the back one is gone						8/6/1984	Philip Ward	27'-6"	8.38	
						11/6/1985	Philip Ward	27'-6"	8.38	
						13/05/1986	Philip Ward	27'-6"	8.38	
						25/05/1987	Philip Ward	27'-1"	8.26	
						25/04/1989	Philip Ward	26'-8"	8.13	
						7/11/1996	P.W. & J.T.	20'-8"	6.3	
						14/05/2003	P.W. & D.C.	12'-1"	3.68	
		N 45 57.770	W 062 42.794	422229.9862	656961.6931	8/7/2014	S.B.	4'-4"	1.32	15.038144
						20/08/2015	Andy MacDonald		1.05	

Panmure Island A K-3	12/3/1984	N 46 08.658	W 062 27.987	441222.992	677231.9726					16.71003
						12/6/1984	Philip Ward	73'-3"	22.33	
						12/6/1985	Philip Ward	73'-3"	22.33	
						10/6/1986	Philip Ward	73'-2"	22.3	
						7/11/1996	P.W. & J.T.	70'-0"	21.34	
						30/12/1998	J.T. & G.W.	67'-7"	20.6	
						19/10/1999	Kathy Candy	66'-0"	20.12	
						14/05/2003	P.W. & D.C.	68'-0"??	20.73	
						8/7/2014	S.B.	66'-5"	20.24	
						20/08/2015	Andy MacDonald		18.04	
K-3 B	14/05/2003					14/05/2003	P.W. & D.C.	35'-6"	10.82	
						Site could not be found				
Savage Harbour K-14	31/10/1984	Ref: N 46 26.045	W 062 51.236	411225.0628	709312.8936					Ref: 11.979596
(Address: 35 vespa lane)		End: N 46 26.066	W 062 51.234	411228.4496	709351.3598	31/10/1984	Philip Ward	191'-0"	58.22	End: 13.317082
						12/6/1985	Philip Ward	188'-9"	57.53	
						29/05/1986	Philip Ward	188'-3"	57.38	
						1/6/1987	Philip Ward	187'-8"	57.2	
						28/04/1989	Philip Ward	181'-8"	55.37	
						17/11/2010	A.M.	153'-6"	46.79	
						16/07/2014	S.B.	135'-0"		
						17/08/2015	Andy MacDonald		40.8	
Seaview Estates Q3 A	30/09/2014	N 46.477983	W -63.45337							
						30/09/2014	Don Jardine, Derek Ellis		12.19	
						27/07/2015	Andy MacDonald		11.8	
B	30/09/2014	N 46.478343	W -63.452873			30/09/2014	Don Jardine, Derek Ellis		12.19	
						27/07/2015	Andy MacDonald		12.62	
C	30/09/2014	N 46.478522	W -63.452162			30/09/2014	Don Jardine, Derek Ellis		12.19	
						27/07/2015	Andy MacDonald		12.19	

Seaview Q-12	6/11/1984	N 46 33.491	W 063 37.235	352415.555	723285.3239					13.951447
						06/11/1984	Philip Ward	89'-0"	27.13	
						13/06/1985	Philip Ward	88'-5"	26.95	
						18/06/1986	Philip Ward	83'-4"	25.4	
						02/05/1989	P.W. & M.M.	82'-0"	24.99	
						08/11/1996	P.W. & J.T.	72'-0"	21.95	
						23/07/1999	J.T. & N.C.	72'-0"	21.95	
						04/05/2011	D.J.	62'-0"	18.898	
						13/06/2014	S.B. & D.C.	75'-6"?	23.01	
						03/08/2015	Andy MacDonald		20.7	
B		N 46.55804	W -63.61906			03/08/2015	Andy MacDonald		10	
St. Peters Harbour K-13	30/10/1984	Ref: N 46 26.517	W 062 44.853	419398.4897	710208.3173					Ref: 0.454692
		End: N 46 26.536	W 062 44.869	419378.1624	710245.0448	30/10/1984	Philip Ward	226'-0"	68.89	End: 6.366924
						12/6/1985	Philip Ward	210'-6"	64.16	
						29/05/1986	Philip Ward	210'-0"	64.01	
						10/8/1998	J.T. & J.D.	155'-9"	47.47	
						3/12/2010	A.M.	150'-0"	45.72	
						9/6/2011	D.J.	140'-0"	42.67	
						16/07/2014	S.B.	130'-0"	39.62	
						17/08/2015	Andy MacDonald		38	
Tea Hill Prov. Park Q-4	8/6/1984	N 46 11.670	W 063 03.757	359166.5982	682673.6171					15.679037
**1999 new bar						8/6/1984	Philip Ward	29'-2"	8.89	
						11/6/1985	Philip Ward	27'-7"	8.41	
						13/5/1986	Philip Ward	27'-5"	8.36	
						30/06/1999	J.T.	16'-8"	5.08	
						13/05/2003	P.W. & D.C.	11'-1"	3.38	
						07/12/2010	D.J.	10'-0"	3.05	
						09/06/2011	D.J.	10'-0"	3.05	
						8/7/2014	S.B.	9'-1"	2.77	
						11/08/2015	Andy MacDonald		2.7	
Union Corner Provincial Park P-5	26/06/1985									
**1996 pins gone						26/06/1985	Philip Ward	24'-2"	7.37	
						22/07/1986	Philip Ward	22'-0"	6.71	
						3/5/1989	Philip Ward	8'-0"	2.44	
						12/11/1996	Philip Ward	Pin Gone	Pins gone	
						Site lost				
B		Ref: N 46 23.251	W 063 59.706	323459.6388	704610.7531	1/7/2014	S.B.	39'-0"	11.89	Ref: 4.607787
		End: N 46 23.243	W 063 59.702	323464.1448	704596.0219	05/08/2015	Andy MacDonald		11.78	End: 5.779029

Wood islands LH Q-2	12/6/1984									
						12/6/1984	Philip Ward	26'-7"	8.1	
)14 new fence installed Previous site removed						11/6/1985	Philip Ward	26'-7"	8.1	
						13/05/1986	Philip Ward	26'-5"	8.05	
						25/05/1987	Philip Ward	25'-2"	7.67	
						25/04/1989	Philip Ward	24'-3"	7.39	
						7/11/1996	P.W. & J.T.	22'-0"	6.71	
						30/12/1998	J.T. & G.W.	21'-8"	6.6	
						14/05/2003	P.W. & D.C.	19'-5"	5.92	
						Site lost				
B	14/05/2003	N 45 56.973	W 062 44.767	419685.1815	655475.7084	14/05/2003	P.W. & D.C.	10'-1"	3.07	14.982303
						8/7/2014	S.B.	3'-2"		14.982303
						Site lost				
C	8/7/2014	N 45 56.990	W 062 44.772	418679.0299	655507.9237	8/7/2014	S.B.	123'-9"	37.72	15.853522
						20/08/2015	Andy MacDonald		35.03	
KN-2	11/6/2012	N 46 31.112	W 063 43.790	344015.7301	720802.9827					13.074191
						6/11/2012	D.C.	95'-0"	28.97	
						22/11/2013	D.C.	94'-3"	28.73	
						13/06/2014	S.B. & D.C.	89'-6"	27.28	
						Site abandoned				
Cape Tryon Q-8	9/7/1984									
						9/7/1984	Philip Ward	59'-9"	18.21	
						13/06/1985	Philip Ward	58'-9"	17.91	
						18/06/1986	Philip Ward	58'-4"	17.78	
						2/5/1989	P.W. & M.M.	58'-4"	17.78	
						27/11/1995	P.W. & A.M.	57'-9"	17.6	
						8/11/1996	P.W. & J.T.	57'-9"	17.6	
						23/07/1999	J.T. & N.C.	56'-3"	17.15	
						4/5/2011	D.J.	56'-3"	17.15	
						6/11/2012	D.C.	53'-9"	16.4	
						22/11/2013	D.C.	53'-8"	16.37	
						13/06/2014	S.B. & D.C.	No tresspassing	No tresspassing	No tresspassing
						Site abandoned				
B						6/11/2012	D.C.	6'-6"	2	
						22/11/2013	D.C.	5'-8"	1.73	
						Site abandoned				

French River Q-7	9/7/1984	N 046 30.626	W 063 29.230	362613.1312	717905.6711					12.445936
						09/07/1984	Philip Ward	114'-6"	34.9	
						13/06/1985	Philip Ward	109'-0"	33.22	
						18/06/1986	Philip Ward	109'-0"	33.22	
						02/05/1989	P.W. & M.M.	105'-0"	32	
						27/11/1995	P.W. & A.M.	101'-0"	30.79	
						08/11/1996	P.W. & J.T.	101'-0"	30.79	
						23/07/1999	J.T. & N.C.	101'-0"	30.79	
						4/5/2011	D.J.	100'-0"	30.48	
						13/06/2014	S.B. & D.C.	98'-10"	30.12	
Gasperaux (Old steel prop.) K-2	8/6/1984									
						8/6/1984	Philip Ward	26'-6"	8.08	
						5/5/1989	S.M.	20'-2"	6.15	
						7/11/1996	P.W. & J.T.	15'-6"	4.72	
						Site abandoned				
Red Pt. Park A K-5 (site #39)	11/6/1984									
						11/6/1984	Philip Ward	39'-4"	11.989	
						12/6/1985	Philip Ward	39'-4"	11.989	
						6/5/1986	Philip Ward	37'-0"	11.28	
						1/6/1987	Philip Ward	34'-7"	10.54	
						28/04/1989	Philip Ward	34'-2"	10.41	
						7/11/1996	P.W. & J.T.	30'-6"	9.3	
						10/8/1998	J.T. & J.D.	28'-5"	8.66	
						17/09/1999	C.M. & D.R.	27'-3"	8.31	
						Site lost				
K-5 B	15/05/2002	N 46 22.117	W 062 07.857	466868.8855	702394.8654	15/05/2002	P.W. & D.C.	46'-6"	14.17	37.060043
						28/09/2011	D.J.	31'-8"	9.65	
						7/7/2014	S.B.	22'-7"	6.88	
Big Pond K-7	30/10/1984	N 46 28.563	W 062.15.334	457167.5687	714188.2157					15.603271
						30/10/1984	Philip Ward	109'-1"	33.25	
						9/7/1985	Philip Ward	108'-7"	33.096	
						29/05/1986	Philip Ward	106'-9"	32.54	
						1/6/1987	Philip Ward	106'-9"	32.54	
						28/04/1989	Philip Ward	104'-2"	31.75	
**2014 Marking pins not found						29/11/1995	Philip Ward	97'-0"	29.57	
Overgrowth of thick spruce						7/11/1996	P.W. & J.T.	96'-0"	29.26	
						10/7/2014	S.B.	No Pins	No pins	

Cable Head East K-11	30/10/1984	N 46 28.001	W 062 34.603	432510.0323	713125.0263					8.860602
						30/10/1984	Philip Ward	63'-0"	19.2	
						9/7/1985	Philip Ward	60'-9"	18.52	
						29/05/1986	Philip Ward	60'-1"	18.31	
						1/6/1987	Philip Ward	58'-10"	17.93	
						28/04/1989	Philip Ward	57'-0"	17.37	
						5/11/1992	Philip Ward	56'-0"	17.07	
						29/11/1995	P.W. & A.M.	54'-0"??	16.46	
						7/11/1996	P.W. & J.T.	54'-0"	16.46	
						10/8/1998	J.T. & J.D.	51'-9"	15.77	
						17/09/1999		50'-0"	15.24	
**2014 Couldn't find the pins						10/7/2014	S.B.	No Pins	No pins	
Possibly a new fence										
Crowbush Golf Course Hole #8	5/11/1993									
incredibly thick thorny brush could only						5/11/1993	P.W. & A.G.	46'-4"	14.12	
find one pin and had to climb on a dune						28/11/1994	P.W. & A.G.	45'-1"	13.74	
to get this measurement						17/05/1996	P.W. & A.G.	40'-0"	12.19	
						6/11/1996	P.W. & A.G.	40'-0"	12.19	
						9/12/1998	P.W. & A.G.	35'-0"	10.67	
						24/11/1999	A.P. Godfrey	26'-0"	7.92	
						29/11/2000	A.P. Godfrey	26'-0"	7.92	
						18/11/2002	A.P. Godfrey	13'-0"	3.96	
						16/07/2014	S.B.	23'-0"		
						Site abandoned				
Crowbush Golf Course Hole #16N	5/11/1993									
**8-10 years ago this beach front was						5/11/1993	P.W. & A.G.	52'-3"	15.93	
armoured by armour rock						18/11/1994	P.W. & A.G.	49'-5"	15.06	
						27/04/1995	P.W. & A.G.	49'-5"	15.06	
						17/05/1996	P.W. & A.G.	45'-5"	13.84	
						6/11/1996	P.W. & A.G.	45'-0"	13.72	
						9/12/1998	A.P. Godfrey	38'-0"	11.58	
						24/11/1999	A.P. Godfrey	33'-0"	10.06	
						29/11/2000	A.P. Godfrey	31'-8"	9.65	
						18/11/2002	A.P. Godfrey	21'-3"	6.48	
						Site abandoned				
Crowbush Golf Course Hole #16W	5/11/1993									
						5/11/1993	P.W. & A.G.	59'-8"	18.19	
						18/11/1994	P.W. & A.G.	59'-4"	18.09	
						17/05/1996	P.W. & A.G.	57'-0"	17.37	
						6/11/1996	P.W. & A.G.	57'-0"	17.37	
						9/12/1998	A.P. Godfrey	51'-8"	15.75	
						24/11/1999	A.P. Godfrey	49'-0"	14.94	
						29/11/2000	A.P. Godfrey	48'-9"	14.86	
						18/11/2002	A.P. Godfrey	40'-0"	12.19	
						Site abandoned				

West Pt. LH NO#	4/5/1999	Ref: N 46 37.218	W 064 23.209	293788.3791	730940.6836					Ref: 6.490945
**in 2010 they installed a sea wall at site		End: N 46 37.215	W 064 23.218	293777.5691	730935.8716	4/5/1999	A.M. & J.T.	65'-0"	19.81	End: 6.604448
						11/7/2014	S.B.			
						Site abandoned				
B		Ref: N 46 37.198	W 064 23.183	293820.8768	730902.6406	11/7/2014	S.B.			Ref: 3.502895
		End: N 46 37.194	W 064 23.189	293812.7177	730896.114	Site abandoned				End: 5.38934
Pauls Bluff LH Victoria P-1	9/7/1984									
						9/17/1984	Philip Ward	25'-5"	7.75	
						9/7/1985	Philip Ward	25'-5"	7.75	
						22/07/1986	Philip Ward	25'-4"	7.72	
						Site abandoned				
Jacques Cartier Prov. Park P-7	8/8/1986									
						8/8/1986	Philip Ward	32'-7"	9.93	
						30/10/1992	Philip Ward	16'-0"	4.88	
						14/10/1999	D.R. & C.M.	Camp Site Moved	Campsite moved	
						Site lost				
Keppoch Hazard Pt. LH Q-5	28/06/1984									
						28/6/1984	Philip Ward	42'-4"	12.9	
						11/6/1985	Philip Ward	42'-4"	12.9	
						13/05/1986	Philip Ward	42'-3"	12.88	
						15/06/1987	Philip Ward	42'-3"	12.88	
						30/12/1998	J.T. & G.W.	30'-4"	9.25	
						30/6/1999	J.T.	30'-0"	9.14	
						13/05/2003	P.W. & D.C.	30'-0"	9.14	
						7/12/2010	D.J.	28'-0"	8.53	
						9/6/2011	D.J.	28'-0"	8.53	
						Site lost				
Covehead Harbour Q-6	9/7/1984	Ref: N 46 25.805	W 062 08.587	388999.842	708867.6337					Ref: 9.522821
		End: N 46 25.819	W 062 08.587	389000.9668	708894.4202	9/7/1984	Philip Ward	126'-0"	38.41	End: 7.413414
						9/7/1985	Philip Ward	124'-0"	37.795	
						18/11/2010	A.M.	87'-0"	26.52	
						16/07/2014	S.B.	76'-0"		
						Site lost				

Point Deroche Q-10	31/10/1984									
**2014 Couldn't find the pins because of						31/10/1984	Philip Ward	120'-0"	36.58	
thick grass on the dune and not wanting to						12/6/1985	Philip Ward	120'-0"	36.58	
damage the dune						1/6/1987	Philip Ward	114'-0"	34.75	
						28/04/1989	Philip Ward	113'-2"	34.49	
						5/11/1992	Philip Ward	106'-5"	32.44	
						6/11/1996	P.W. & A.G.	103'-0"	31.39	
						16/07/2014	S.B.	Couldn't find the pins	Couldn't find the pins	
						Site lost				
Rice Pt. Q-13	16/07/1985									
						16/07/1985	Philip Ward	41'-7"	12.68	
						3/5/1989	P.W. & K.C.	39'-10"	12.14	
						12/11/1996	P.W. & J.T.	39'-8"	12.09	
						12/108/1999	Kathy Bunnie	39'-6"	12.04	
						Site lost				